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SCIENTIFIC AMERICAN

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1,500 feet over Kuala Lumpur

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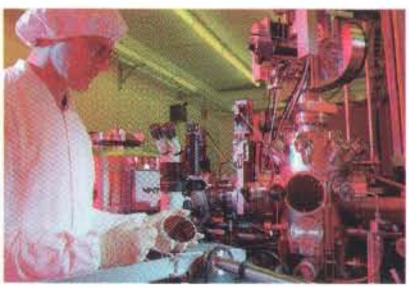
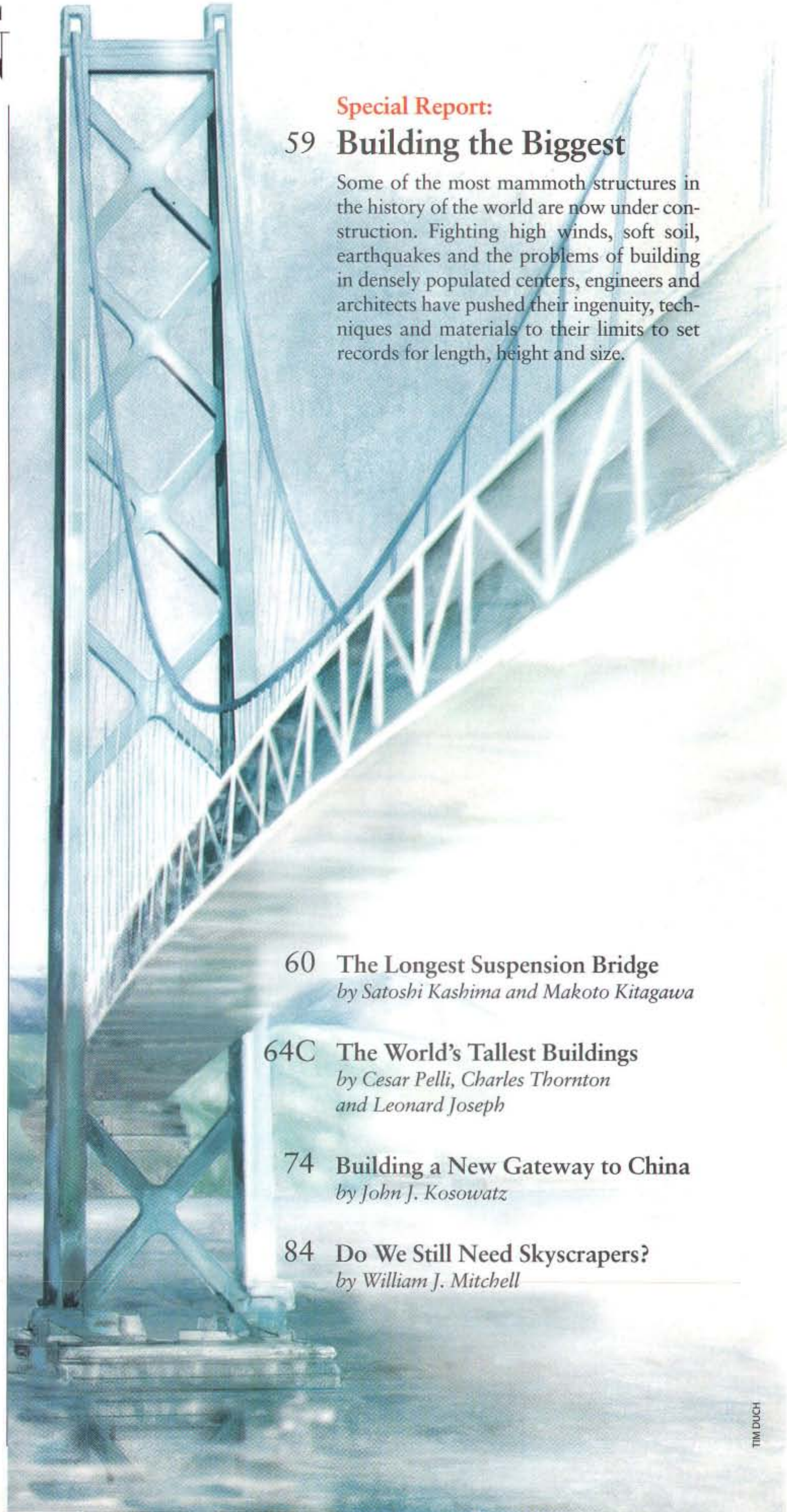
redefine
television

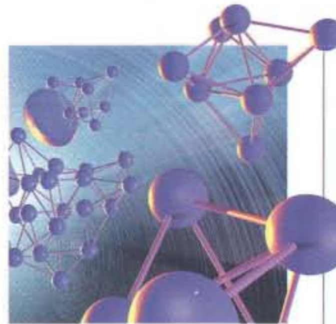
SCIENTIFIC AMERICAN

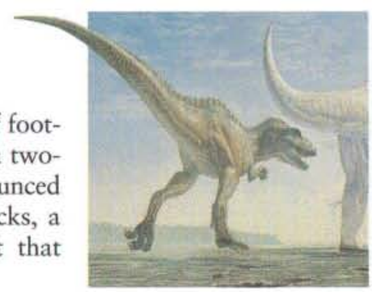
December 1997 Volume 277 Number 6

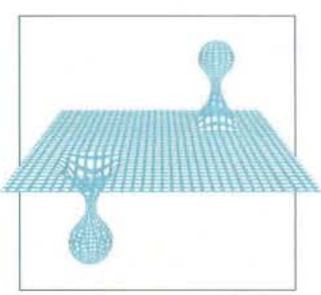




TIM DUCH







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REVIEWS AND COMMENTARIES

About the Cover

From near the pinnacle of one of the 88-story Petronas Twin Towers in Malaysia, the magnitude of this engineering feat is obvious. Photograph by J. Apicella, Cesar Pelli & Associates.

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KRISTINA WIKLUND
ENGINEER:
INTERIOR SAFETY

The new Saab 9-5 is engineered for intuitive driving. In our efforts to further enhance car/driver interaction, we have re-thought every aspect of this automobile, including one which is close to every driver – the seat.

We started by placing the driver's seat as close to the car's centre of gravity as possible.

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And while all performance cars are engineered to keep the engine and other vital components at optimal operating temperatures – how many afford the same consideration to the driver? We do, with a unique active ventilation system built into the seat. This keeps the driver feeling refreshed and helps reduce fatigue on long drives.

Naturally, our driver's seat provides proper support for your back. But it offers one more orthopedic advantage that is a first for the automotive industry: an advanced head restraint system which can actually prevent whiplash in the event of a rear-end collision.

To learn more, stop by your local Saab dealer and discover the rest of the new 9-5. Because it's only after you take a seat in this car that you begin to understand our belief:

There should be no forces outside your control.

It sets a new engineering standard for safety, comfort and intuitive feel for the road. (And that's just the seat.)

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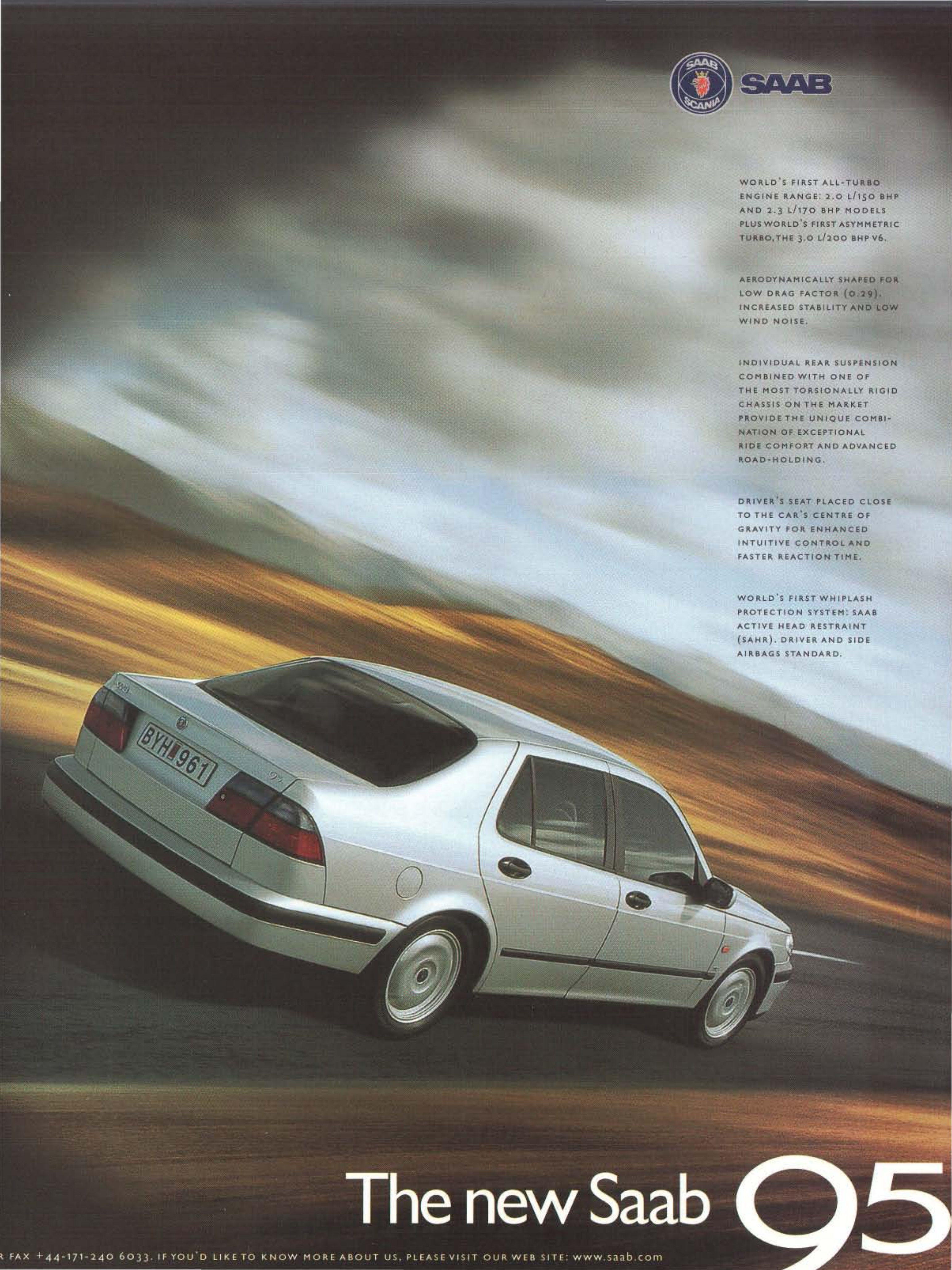
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FROM THE EDITORS

Building Excitement

One of the most popular children's videos of recent years had no singing dinosaurs, spaceships, talking dogs or cartoon characters. What it had was bulldozers. And giant cranes, and backhoes, and wrecking balls, and other pieces of heavy equipment for putting up buildings or ripping them down. I like the timelessness of that. Today we can take our entertainment from virtual reality and sometimes do, but the fences around construction sites still have windows cut in them for the sake of curious pedestrians, and they never stand empty.

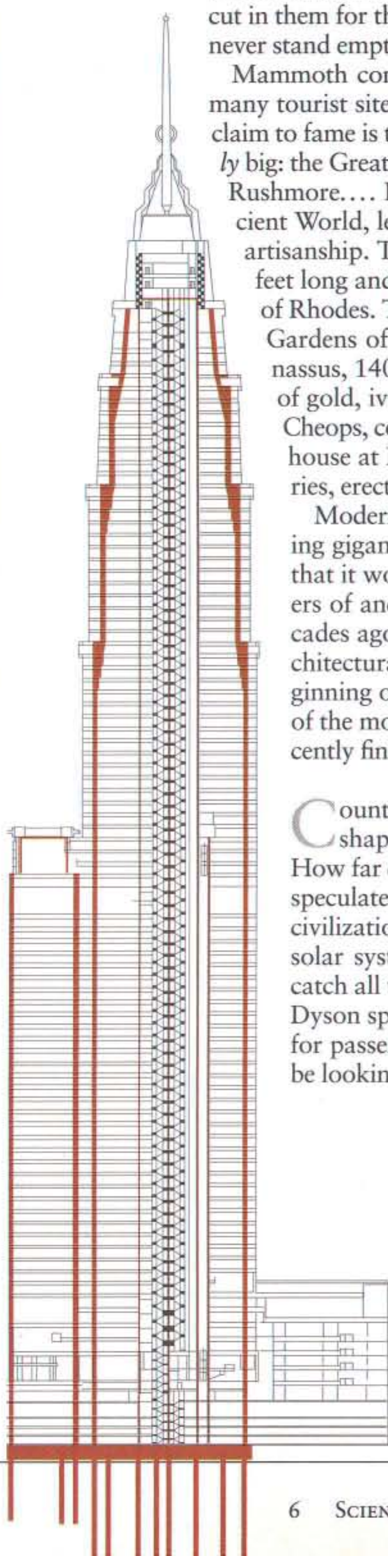
Mammoth construction is enthralling; think of how many tourist sites are built around things whose major claim to fame is that they are not just big but *stupefyingly* big: the Great Wall of China, the Eiffel Tower, Mount Rushmore.... Look at the Seven Wonders of the Ancient World, legendary for their size as much as their artisanship. The Temple of Artemis in Ephesus, 425 feet long and 220 feet wide. The 100-foot Colossus of Rhodes. The five 50-foot terraces of the Hanging Gardens of Babylon. The Mausoleum at Halicarnassus, 140 feet high. The Olympian Zeus, 40 feet of gold, ivory and marble. The Great Pyramid of Cheops, covering 13 acres. The 500-foot-tall lighthouse at Pharos. By the standards of past centuries, erecting such monuments was heroic.

Modern architects and engineers are still building gigantic structures, often on a scale so huge that it would have dazzled not merely the builders of ancient times but even those of a few decades ago. In our special report on the latest architectural Wonders of the Modern World, beginning on page 59, we take a look at just a few of the most gigantic civil engineering projects recently finished or nearing completion.

Count on more and larger projects to take shape in the decades and centuries ahead. How far can things go? Physicist Freeman Dyson speculated years ago that a sufficiently advanced civilization might disassemble the planets of our solar system and construct a spherical shell to catch all the sun's energy. If they were building a Dyson sphere, would they have to cut holes in it for passersby? And who do you suppose would be looking in?

John Rennie

JOHN RENNIE, *Editor in Chief*
editors@sciam.com



CESAR PELLI & ASSOCIATES

PETRONAS TOWER...
In every era, visionaries have built huge marvels of the engineering arts.

Probably the best beer in the world.

LETTERS TO THE EDITORS

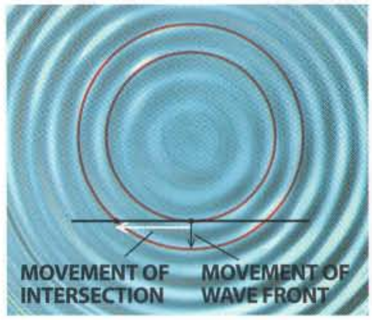
FASTER THAN LIGHT

I was stunned by your carelessness in allowing the statement in the caption on page 38 of your August issue that anything can travel faster than the speed of light ["Lightning between Earth and Space," by Stephen B. Mende, Davis D. Sentman and Eugene M. Wescott]. Unless the laws of general and special relativity have been repealed, I suggest an explanation and correction of this error be made in your next issue.

STEVEN E. BOLLT
Bethesda, Md.

The Editors reply:

Many readers have wondered about the statement in the caption, but it is correct. It does not contradict the laws of relativity, because in the described situation, no physical object or information-carrying signal is moving faster than light. Rather what enlarges faster than light is the ring-shaped intersection of a horizontal layer with a sphere expanding at the speed of light. (Recent measurements of these rings, in fact, show the rate of lateral widening to be about three times light speed.) A more commonplace example may be helpful. Drop a pebble into a pond. The intersection of the resulting ripples with a horizontal line (*above*) enlarges much faster (*white arrow*) than the rings themselves do (*black arrow*).



JOHNNY JOHNSON

DOLLY'S DNA

I just read "Mitochondrial DNA in Aging and Disease," by Douglas C. Wallace [August], and it occurred to me that Dolly, the famous cloned sheep, would have actually inherited mitochondrial DNA from the egg cell donor. From what I understand of the cloning process, the nucleus of a cell from the adult sheep that was to be cloned was inserted into an egg cell from another ewe. So Dolly would have inherited some genes from the mitochondria in the egg cell, right?

DANA DORRITY
Phoenicia, N.Y.

Wallace replies:

Dorrity makes an insightful comment—Dolly, a clone of a Finn Dorset ewe, was created by the fusion of a whole mammary gland cell from the Finn Dorset ewe with an enucleated egg cell from a Scottish Blackface ewe. This suggests that most of Dolly's mitochondrial DNA would derive from the Blackface ewe. Because the mammary cell from the Finn Dorset ewe also contained mitochondria, however, it is possible that Dolly may have inherited mitochondrial DNA from both sheep lines.

LANDAU AND THE KGB

As someone who met Lev Landau in 1947 and who had many scientific and political discussions with him during the 1950s, I do not share the opinion that Landau participated in preparing the anti-Stalin leaflet described in Gennady Gorelik's article "The Top-Secret Life of Lev Landau" [August]. The most plausible explanation of this leaflet is that it was a forgery by the KGB. By the end of the 1940s and into the 1950s, Landau had no illusions about communism, but he would not have been foolish enough to prepare the leaflet, which could only have been written by someone who wished to become a martyr. All his life, Landau was a pragmatic and logical man but not a political visionary. Physics was first for him.

BORIS L. IOFFE
Institute of Theoretical
and Experimental Physics
Moscow

Gorelik replies:

Ioffe and I agree about the late anticommunist phase of Landau's life, but for the early phase of his life, during the 1930s, I rely on testimonies of people who knew him then. Both Hendrik Casimir (see his 1983 book *Haphazard Reality,* published by Harper & Row) and Edward Teller witnessed Landau as a revolutionary, enthusiastic about the Soviet regime. It is beyond the scope of this page to document the extensive historical evidence that supports my belief in the authenticity of the seemingly unbelievable leaflet that connected two very different phases of Landau's life.

REMEMBRANCE OF THINGS PAST

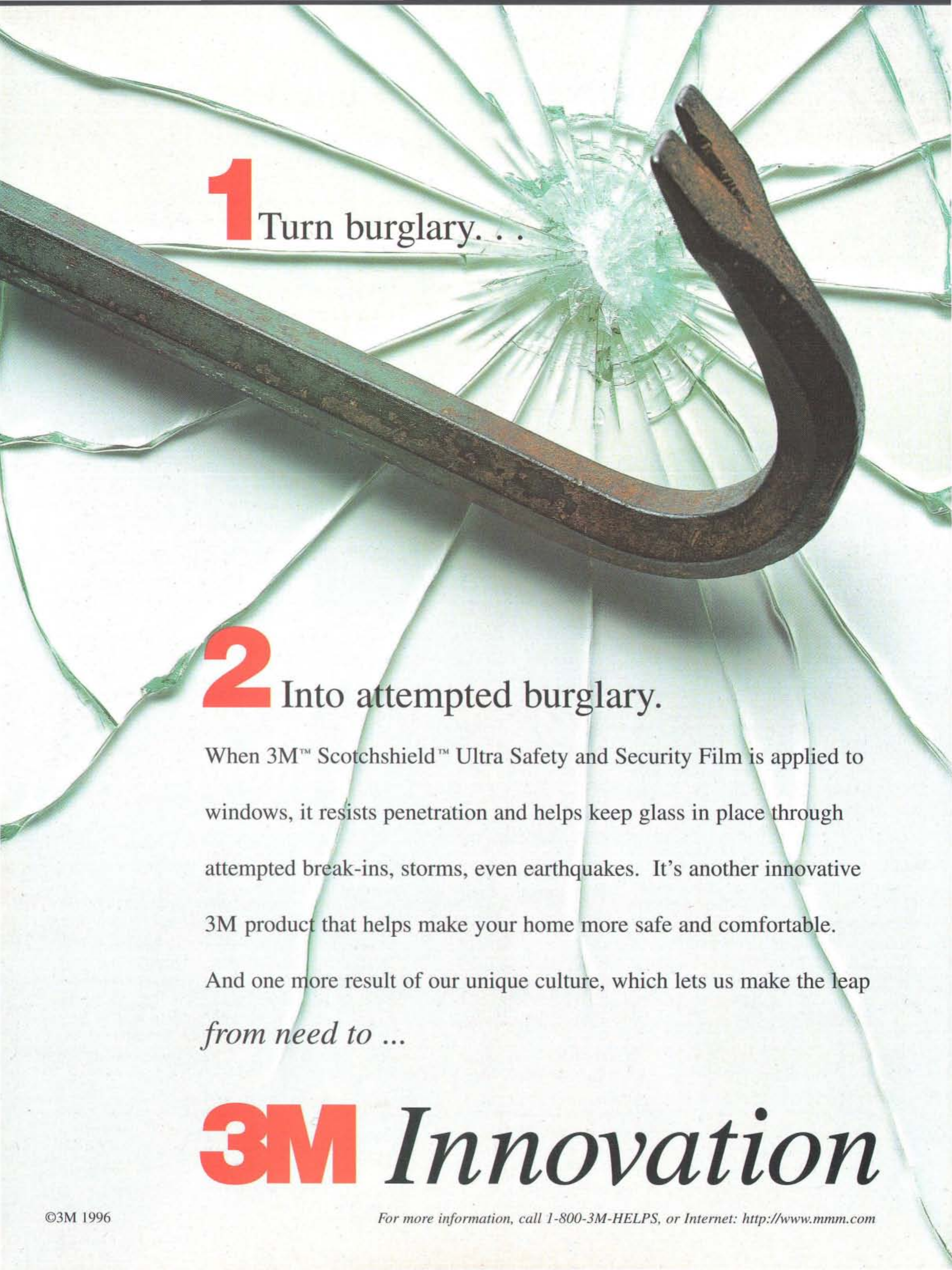
Tim Beardsley's review of recent imaging and scanning experiments designed to elucidate brain function ["Trends in Neuroscience: The Machinery of Thought," August] reveals both the strengths and weaknesses of these tactics. PET scans, CT scans and MRI represent a huge leap forward in technology. But contemporary research still tells us only where something happens in the brain, not what the actual mechanisms are for recognizing, remembering and so on. And that, of course, is what we really want to know.

MURRAY S. WORK
Carmichael, Calif.

Letters to the editors should be sent by e-mail to editors@sciam.com or by post to Scientific American, 415 Madison Ave., New York, NY 10017. Letters may be edited for length and clarity.

ERRATA

In the article "Gamma-Ray Bursts" [July], it was stated that the HETE spacecraft failed to separate from its launch rocket. In fact, the third stage of the Pegasus XL launch vehicle failed to release the HETE satellite. The Manicouagan crater mentioned in the review "Dusk of the Dinosaurs" [Reviews and Commentaries, September] is in Quebec, not British Columbia. And the loss of electricity described in "Leaky Electricity" [News and Analysis, "In Brief," August] is 50 watts per house, or 450 kilowatt-hours a year.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50, 100 AND 150 YEARS AGO

DECEMBER 1947

NEW 3-D PHOTOGRAPHY—"A new type of glass, containing infinitesimal metallic particles throughout its mass, possesses photo-sensitivity to ultra-violet light and offers new possibilities as a photographic material. The images are formed in color and in three dimensions by exposing the glass to ultra-violet light through a negative. To develop the image, the exposed glass is subjected to a temperature of about 1,000 degrees Fahrenheit. Once developed, the image is extremely permanent and is free from the graininess encountered with some silver emulsions."

HARDENED ELECTRONICS—"When a delicate electronic circuit is subjected to the most violent shock and vibration, to heavy moisture and to corrosive atmospheres, the problem of stabilization assumes Gargantuan dimensions. It was in search of an answer that the National Bureau of Standards turned to a technique of embedding, or 'potting,' entire electronic circuits in plastics, and developed a new resin for that purpose. Called the NBS Casting Resin, this new material minimizes electrical loss and does not shrink on gelling."

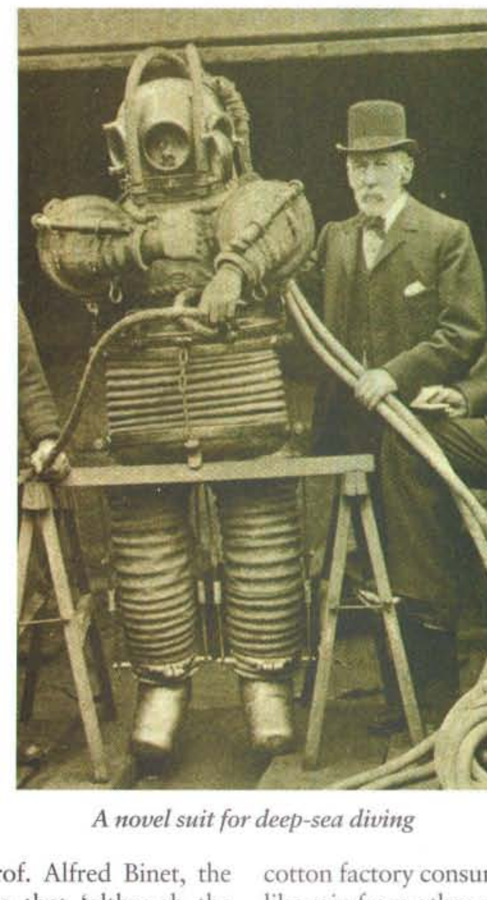
DECEMBER 1897

DARWIN RIGHT AGAIN—"The scientific expedition that was dispatched to the Ellice Islands by the Sydney Geographical Society has confirmed Darwin's theory of the formation of coral islands [that reefs were created over aeons by coral polyps building successive layers on subsiding landmasses]. Reports from Samoa are that the diamond drill went down 557 feet in the coral without reaching the bottom. Beyond 487 feet, the results strongly favor Darwin's theory, though a final judgment depends upon microscopic examination of the drill cores."

PIONEERING PSYCHOLOGY—"Prof. Alfred Binet, the celebrated French psychologist, notes that 'although the methods used for measuring the memory may have been crude, as they still are, it is nevertheless a great advance to be able to introduce the concept of measurement into this problem at all. So far, attempts have been made to measure but one kind of memory—the direct faculty of acquisition. The experiments deal with the number of memory images that can be stored up at a single trial.' The average educated adult retains seven figures; a child of ten years old retains six." [*Editors' note: Binet's work led him to develop the first intelligence test.*]

FAKE OYSTERS—"Real oysters are expensive in Paris, and so artificial oysters on the half shell have been invented, which are sold at twenty cents a dozen, and so cleverly made to look nice and fresh that, once lemon juice or vinegar has been added, they cannot be distinguished from the real article. The only genuine thing about these oysters is the shell, the manufacturers buying second hand shells at a small cost, and fastening the spurious oyster in place with a tasteless paste."

UNDER THE SEA—"We present a photograph of a diver clad in the new Buchanan-Gordon diving dress. The patentees, after a number of successful experiments in Australia, where the dress is used in connection with pearl fisheries, brought a couple of dresses to London. They received every assistance from that famous firm of submarine engineers Messrs. Siebe, Gorman & Company, London, in designing the present day dress. The helmet, which descends to the waist in one piece of solid copper, weighs no less than 250 lbs., while the dress weighs 500 lbs., and enables the diver to breathe at normal air pressure. The dress is also equipped with a telephone to the surface."



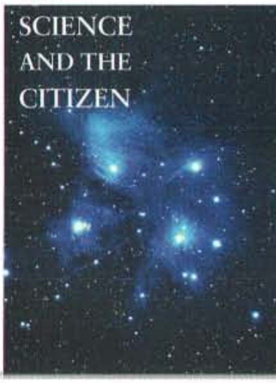
A novel suit for deep-sea diving

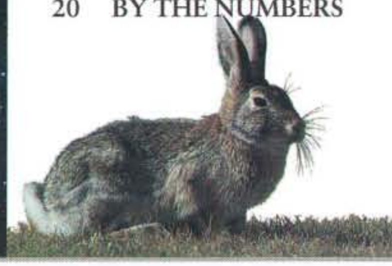
DECEMBER 1847

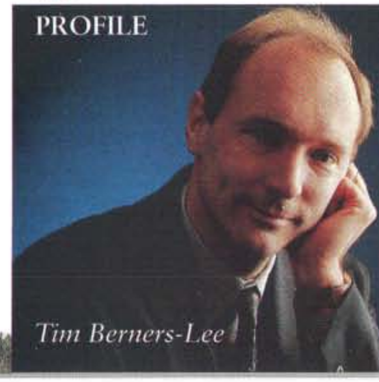
SMOKE SCRUBBER—"The Pittsburg Gazette says: Messrs. Blackstock and Co. have made a trial of a smoke preventive apparatus, in their Cotton Factory in Allegany city. The experiment has proved successful. While the chimneys of the neighboring factories were vomiting forth clouds of black smoke that darkened the atmosphere on one of the finest Indian Summer days we have seen, the Smoke Preventive in the cotton factory consumed all the parts of smoke that dropped like rain from other points around us."

ANCIENT SCIENCE—"A four-wheeled carriage with brown ornaments and iron wheels has been recently discovered in a three-story house dug out at Pompeii. It is our opinion that when the Roman Empire was overthrown by the Goths, the Romans were nearly as far advanced in civilization as we are at the present moment."

NEWS AND ANALYSIS







Tim Berners-Lee

IN FOCUS

THE BIG SHRINK

Federal labs are developing new chipmaking techniques. Who will reap the benefits?

The explosive growth of cheap computing power has made possible not only virtual-reality headsets and the key-chain pet Tamagotchi but also "smart" missiles and advanced radar systems, among other applications. Not surprisingly, governments consider the multimillion-dollar machines that fabricate semiconductor chips, known as steppers, to be militarily as well as commercially critical.

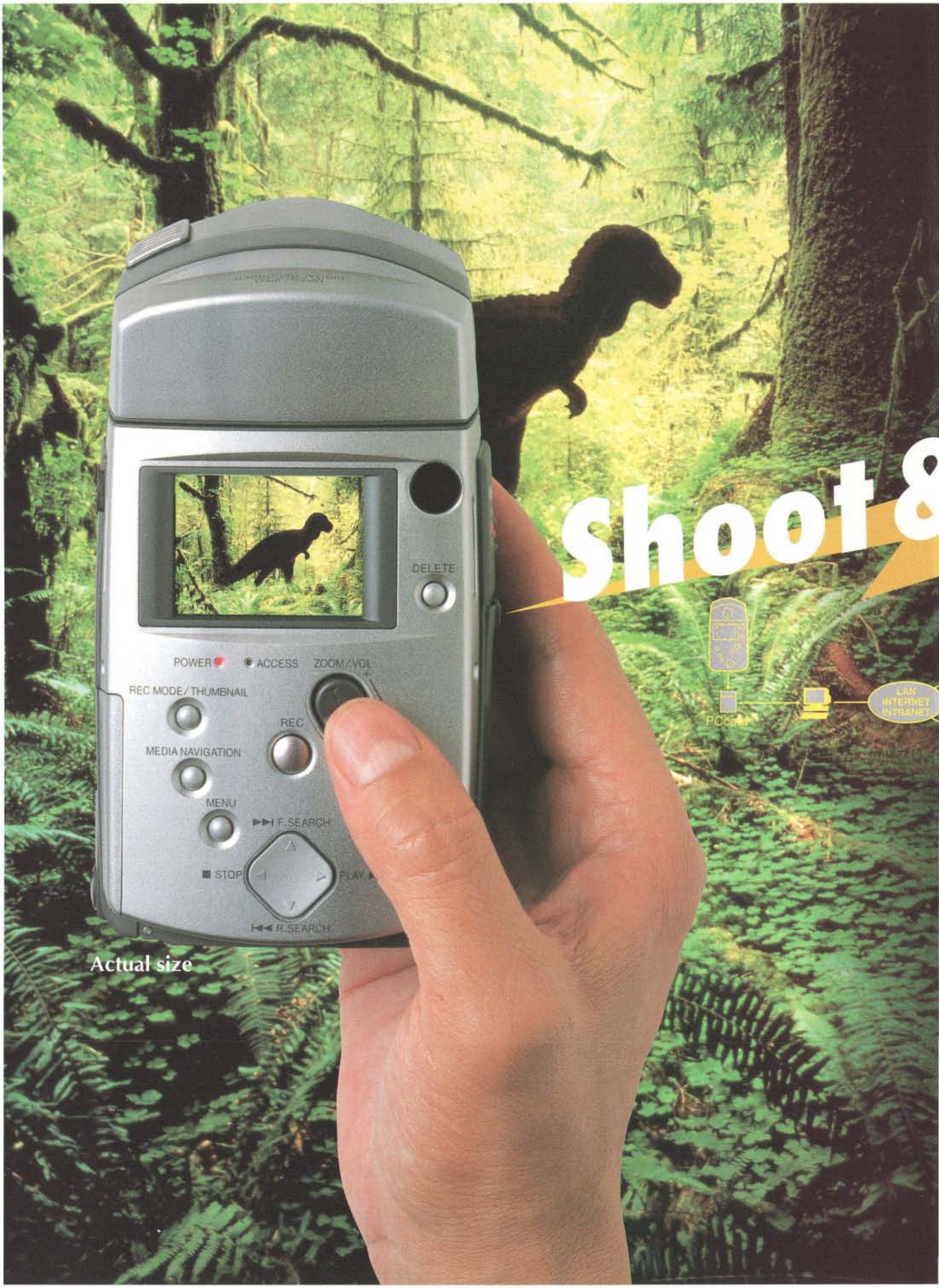
The U.S. supplies nearly half the world's chips but provides only 9 percent of the steppers. Simmering strategic and trade concerns about semiconductor fabrication technology have recently come to a boil. The heat was turned up with the announcement in September that a consortium formed by Intel and two other U.S. chip manufacturers will pump $250 million into the Department of Energy's weapons laboratories to develop a radically new fabrication technology. Critics, however, charge that the technique will be exploited largely by foreign companies and that the plan neglects national security concerns.

SANDIA NATIONAL LABORATORIES

EXTREME ULTRAVIOLET lithography system at Sandia National Laboratories became, in 1996, the first to pattern a fully functional transistor on a silicon wafer using this low-wavelength light. Lines etched with extreme ultraviolet light (inset) *are less than 0.15 micron wide.*

The new approach, known as extreme ultraviolet (EUV) lithography, could open new vistas in chip design, allowing them to be made with conducting channels less than 0.1 micron in width, or below one thousandth the width of a human hair. High-tech chips today have channel widths of 0.25 micron. EUV lithography should make it possible to pack a billion transistors onto each silicon sliver, instead of mere millions, and would slash the distances electrical signals have to travel. The result could be low-cost memories that store 1,000 times as much information and processors that run 100 times faster than today's versions.

Steppers now employ visible or near-ultraviolet light to "print" circuit patterns. Light is shone through a mask, and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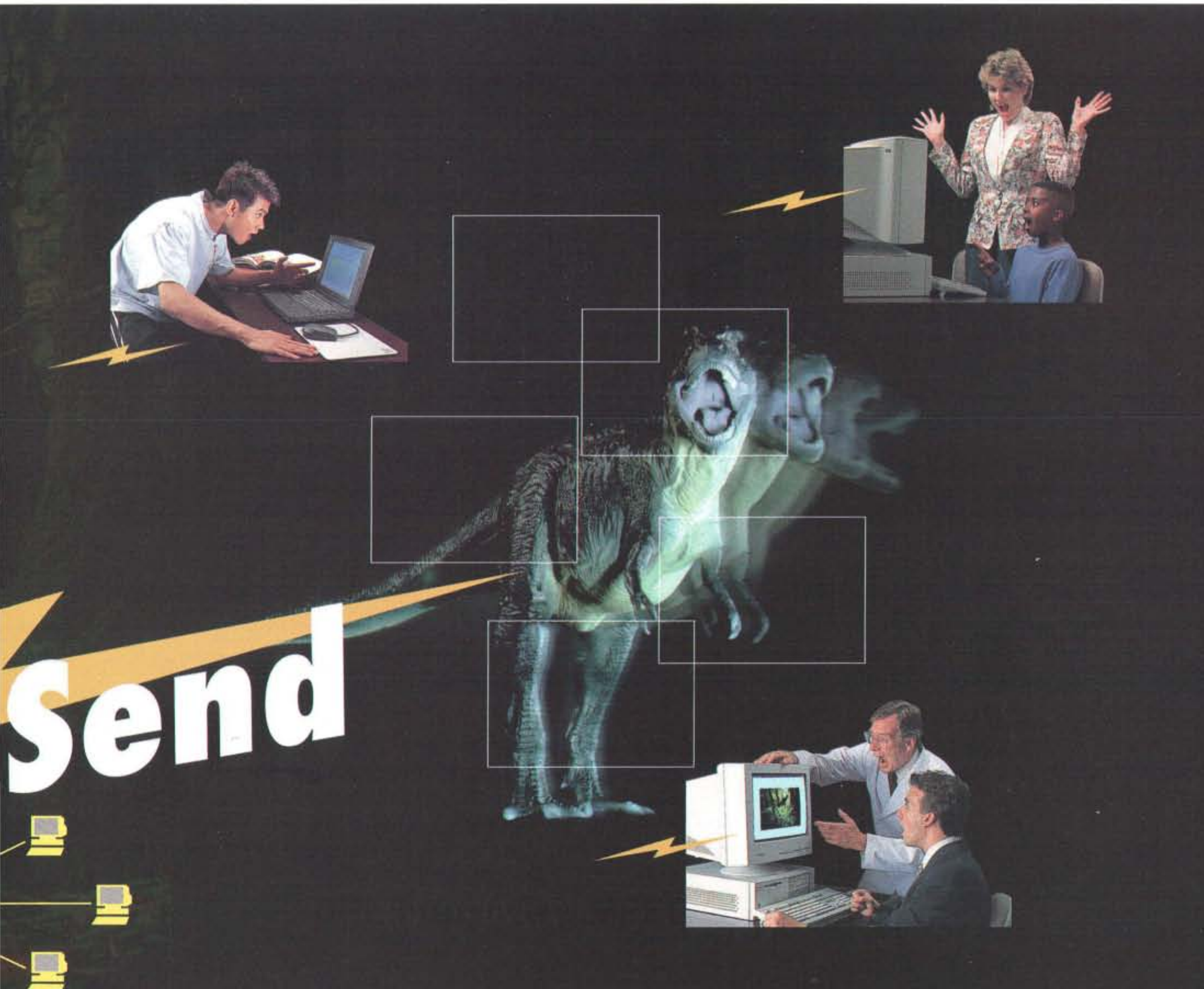

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The MP-EG1A is the world's first MPEG1/JPEG recorder for PCs. Images can be encoded into the MPEG1 format in real time and recorded onto a Windows®-compatible PC card hard disk, giving you an instant plug-and-play computer connection for effortless drag-and-drop copying of your video files. The completed video — for report, presentation, catalog or website — can then be sent anywhere in the world. It's so easy — just shoot, copy and send.

● 20 minutes of full-motion video and audio in MPEG1. ● 3,000 still images in JPEG. ● 1,000 still images, each with 10 seconds of audio, in JPEG and MPEG1 Audio. ● Simple file transfer with PC card hard disk (Type III). No file transition time. No file conversion. ● Dimensions and weight: 83 x 143 x 56 mm (3.3" x 5.6" x 2.3") [W x H x D], 540g (19.3oz).

For more details on the MP-EG1A, please visit our website—

URL:http://www.MPEGCam.com

HITACHI

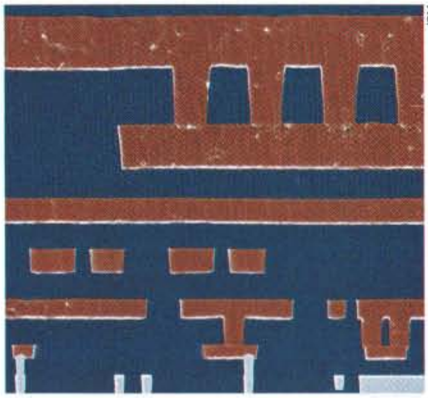
A TOTALLY NEW VISION

Other Routes to Speed

Improved lithography is not the only way to make chips more powerful. Many manufacturers have high hopes for using copper, rather than aluminum, to build the internal wiring that connects the transistors on a chip.

Copper wires can be made thinner, leading to more tightly packed circuits. But researchers have been stymied by difficulties laying down copper on silicon. Copper atoms diffuse into the semiconductor, ruining its electrical properties [see "Under the Wire," Technology and Business, May].

IBM announced in October that it has a patented solution: a sealant that keeps copper in its place. The company says its copper technique should reduce chip prices by 20 percent while increasing their power by 40 percent. It plans to start shipping copper-based products in the first half of 1998.



IBM

COPPER CONNECTIONS conduct quickly.

Intel, meanwhile, has announced a new type of "flash" memory chip in which each transistor can precisely hold four different amounts of charge. In this way, it can store two bits of information instead of one, thus doubling the devices' capacity. Flash memories, which retain data during power outages, account for only a few percent of the chip market. But they are its fastest-growing segment. *—T.M.B.*

specialized lenses shrink the resulting image fourfold before it is projected onto a prepared silicon surface. Since the 1960s the number of transistors that can be crammed onto a chip has doubled every 18 months. But engineers agree that the end is in sight for contemporary methods. Tinier features need shorter-wavelength light to print them, but lenses do not transmit light with a wavelength less than about 0.19 micron. With current techniques that means a minimum channel size of about 0.13 micron, according to Steven R. J. Brueck of the University of New Mexico.

EUV lithography, which arose in part from "Star Wars" research, has been demonstrated in the laboratory. It bypasses the 0.13-micron limit by employing light with a wavelength about $^1/_{30}$ of that now used in chip manufacture. But there are many engineering hurdles facing EUV before it can be employed routinely. Perhaps the biggest challenge is making the optics, according to G. Dan Hutcheson of VLSI Research. They are high-precision aspherical mirrors coated with 40 or so alternating layers of molybdenum and silicon.

Other companies are pursuing alternative chip fabrication technologies. Several are using electrons in different ways, and IBM wants to use x-rays, which have an even shorter wavelength than EUV. But although x-ray lithography works in a research setting, the company has failed to turn it into a commercial proposition, Hutcheson notes.

If EUV steppers are successfully built, the semiconductor industry would have years more of dizzying advances. Besides Intel, Advanced Micro Devices and Motorola contributed small amounts to the original consortium, called the EUV Limited Liability Company. Energy Secretary Federico Peña said in September that equipment producers who license technology from the consortium will be required to manufacture in the U.S. for two years.

The critics complain that the consortium's business plan will mean that Nikon in Japan and ASML in the Netherlands will end up making most EUV-technology steppers. Leading the protesters has been Arthur W. Zafiropoulo, head of Ultratech Stepper in San Jose, Calif. Zafiropoulo insists that the consortium plan "allows the systems integration of the EUV technology to be turned over to foreign hands."

The prospect of U.S. weapons labs developing manufacturing techniques for use in Japan and Europe has also alarmed four Democratic congressional representatives, who have called on the Clinton administration to reexamine the scheme. The consortium would support about 90 scientists for three years, principally at Sandia National Laboratories in Albuquerque, N.M., and Lawrence Livermore National Laboratory in Livermore, Calif. But the arrangement "would result in serious and unprecedented access to U.S. national defense labs by foreign companies," wrote Representatives John D. Dingell of Michigan, George E. Brown of California, Ron Klink of Pennsylvania and Tim Roemer of Indiana in a letter to Peña on October 9.

The letter notes that taxpayers are contributing about $34 million to the EUV development effort in the form of DOE overhead costs. Moreover, the legislators maintain that an "unprecedented provision" in the agreement would allow licensees of EUV technology to avoid the requirement that they manufacture for two years in the U.S. Instead they could propose an alternative plan.

The EUV consortium has set off national security alarms in the Commerce Department. State-of-the-art lithographic equipment is controlled by the U.S. and its allies to keep it out of the hands of hostile nations. With EUV, "are there national security implications for this technology that would cause us to want to control [it] more tightly?" asks William A. Reinsch, undersecretary of commerce for export administration. Reinsch says he did not learn about the agreement until after it was signed—an event that took place quietly this past March. He is now trying to foster a domestic group of companies to manufacture EUV equipment.

Intel's Sander H. Wilson, director of the EUV consortium's business plan, defends his group's right to allow overseas companies access to EUV technology. The federal government cut off funding for lithography at the weapons labs in 1996, he points out; the consortium has thus preserved a "national treasure." Wilson insists that "you need to gain economies of scale to develop the tools." And the fact is that Nikon, ASML and Canon in Japan do manufacture more than 90 percent of the world's steppers. The U.S. may have to decide whether to support jobs overseas in order to support jobs at home. *—Tim Beardsley in Washington, D.C.*

PALEONTOLOGY

NO BONES ABOUT IT

T. rex *Sue highlights the battle over private collecting on public land*

On October 4 one of the most famous fossils in the world went on the auction block. The sale, at Sotheby's in New York City, opened with a bid of $500,000; just over nine minutes later, Sue—the largest and most complete *Tyrannosaurus rex* skeleton ever found—sold for $7.6 million (including Sotheby's commission, the total price topped $8.36 million). "She will spend her next birthday in her new home on the shores of Lake Michigan in Chicago, at the Field Museum," announced Richard Gray, president of the Art Dealers Association of America, who represented the museum and outbid eight others. Although Sue's destiny is settled, the issues she has raised linger. To many academic paleontologists, the sale highlights the troubling commercial trade in fossils.

The *T. rex* was discovered in 1990 on a South Dakota ranch by Susan Hendrickson, a collector working with the Black Hills Institute of Geological Research in Hill City, a commercial fossil outfit. The institute paid the landowner, Maurice Williams, $5,000 for the right to take the fossil, a deal determined by the courts in 1994 to be illegal. Because Williams's land is held in trust by the U.S. government (he is a Cheyenne River Sioux), he cannot sell it—or anything on it—without federal permission. The courts subsequently awarded Williams possession of the dinosaur, dubbed for its discoverer, and the government decided to auction the fossil on his behalf.

John J. Flynn of the Field Museum says the remaining preparation of the skeleton should take two years to complete. Sue will go on display at the museum in 2000, and two life-size casts of the *T. rex* will travel to museums around the world. Another will be on display at DinoLand USA in Disney's newest theme park in Florida, Animal Kingdom.

Although most paleontologists were relieved that Sue will go to a museum, many worry that the auction established a dangerous precedent. "Museums bidding against themselves is a ridiculous idea," asserts Louis L. Jacobs, president of the Society of Vertebrate Paleontology (SVP). And the high-profile sale sets the benchmark, observes Claudia Florian of Phillips Fine Art Auctioneers in New York City. Many museums simply cannot afford to pay such astronomical prices. (The Chicago museum got help from various donors, including the California State University system, Walt Disney World Resort and McDonald's.) "There's no way that setting a high price on fossils ultimately helps the profession, or museums, or education. It contributes to the mind-set that our national treasures are up for grabs to the highest bidder," Jacobs argues.

JEFF CHRISTENSEN *Gamma Liaison*

***NEW CARETAKER OF SUE** is the Field Museum in Chicago, represented by* (left to right) *John McCarter, Peter Crane and Richard Gray at the Sotheby's auction.*

Sue's sale also raises the question of access to public lands. Right now, when it comes to vertebrate fossils, only academics can get the necessary permits. But most commercial fossil operations would like to see public land open to all collectors—as promised by the Fossil Preservation Act of 1996, which failed to make it to committee before Congress recessed earlier this year. Marion K. Zenker of the American Land Access Association, an amateur fossil-collecting group, expects the bill to be reintroduced. Zenker, who also works for the Black Hills Institute, says such legislation is necessary because large numbers of fossils erode away on public land. The reason: there simply are not enough professional paleontologists to collect them. "If everyone were allowed to collect, so much more would be found, and science would gain by measures beyond imagination," she insists.

Commercial paleontologist Michael Triebold concurs but also thinks collectors should be held to strict standards, such as a demonstrated ability to remove fossils carefully and with respect for the science. "Requirements should include things such as site mapping; photographing before, during and after; proper field techniques; and saving contextual data," he states. If those rules are satisfied, he believes, then commercial collectors should be given access to public lands and the right to dispose of fossils as they see fit, perhaps allowing for a fee to go to the land management agency. The only exception would be if the fossil represented a new species.

Some insist that even framing the battle as commerce versus academia is misleading. "Not all fossils have scientific value, and most scientifically important fossils have no commercial value. Only seldom does a fossil have the two," maintains Henry Galiano, owner of Maxilla and Mandible, a New York City fossil store. Terry Wentz of the Black Hills Institute adds, "Just because it went into public hands doesn't necessarily mean that the specimen would be taken care of well. It's the individual people involved with the fossils that make the difference."

Still, Jacobs and the SVP take a hard line: "What we have to do is use the lesson of Sue to make sure that vertebrate fossils are never allowed to be commercially collected from public lands, because what belongs to the public should not be sold to the public." The fight for Sue may be over, but the battle over bones wages on. *—Karin Vergoth*

IN BRIEF

$E = mc^2$, Really

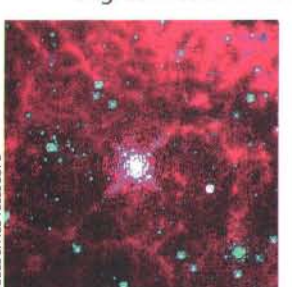
Converting matter into light is a simple trick compared with the flip side of Einstein's famed equation—or turning light into matter. To do so requires far more energy than physicists have managed to generate in the laboratory. But a team at the Stanford Linear Accelerator Center recently succeeded by aiming terawatt laser light into the accelerator's tightly focused electron beam. Some of the laser photons scattered backward and changed into high-energy gamma-ray photons. These photons in turn collided with other laser photons and produced electron-positron pairs.

Vodka Woes

Between 1984 and 1994 life expectancy in Russia for both men and women rose briefly and then plummeted. In a new study demographers led by D. A. Leon of the London School of Hygiene and Tropical Medicine credit the extra deaths to heavy drinking. The group found that rates of cancer-related deaths held steady during the decade it studied. And although tuberculosis became more prevalent and the health care system changed during the same period—factors that may have affected life expectancy—the incidence of deaths from alcohol-related diseases, accidents and violence rose most dramatically.

The Biggest Star

So named for the shape of its nebula, the Pistol Star, hidden away amid dust clouds in the center of the Milky Way, has stunned astronomers with its enormity: it appears to be 100 times larger than the sun and 10 million times brighter. Researchers from the Space



HUBBLE SPACE TELESCOPE

Telescope Science Institute and the University of California at Los Angeles first captured Pistol's image in October, using the Hubble Space Telescope's near-infrared camera and multiobject spectrometer, which astronauts installed last year. Now theorists must struggle to reconcile Pistol's seeming size with notions of star formation, which generally do not predict stars that big.

HEALTH

SAY THAT AGAIN?

Researchers plan to see if cell phones could affect memory

Regulators in Europe are taking a harder look at mobile phone safety. Although claims that fields from power lines could cause cancer have been authoritatively refuted by the U.S. National Research Council (NRC), that body acknowledged that sufficiently strong electrical and magnetic fields can have behavioral effects on animals. Now experiments on mice conducted at the National Radiological Protection Board in the U.K. have confirmed an apparent effect of magnetic fields on learning in animals that was first identified by a U.S. researcher.

In 1994 Henry Lai of the University of Washington showed that microwave radiation seems to slow down learning in rats. He placed rats in a maze that had 12 arms leading from it, each baited at its far end with a morsel of food. After a few days of daily training sessions, rats learned to visit each arm once only.

Lai and his colleagues observed that exposing rats to 45 minutes of pulsed microwave radiation each day before putting them in the apparatus slowed down their mastering of the task. The effect occurred when the amount of microwave energy absorbed in the experimental animals each minute was close to levels that might be absorbed by the brain of a cellular phone user. The effect of the fields could be eliminated by pretreating the rats with drugs affecting two neurochemical systems in the brain: the endogenous opioid system and the cholinergic system. Lai thus proposed that fields can affect those brain systems.

Lai, who last year demonstrated a similar behavioral effect from exposure to 60-hertz power-line-frequency fields, also has indications that microwave-frequency fields can cause DNA breaks. Moreover, he has some evidence that such effects may be cumulative. Lai speculates that if cellular phones caused forgetfulness, they might cause accidents, for example, among drivers. But he emphasizes that the microwaves in his experiments were of a higher frequency than those used by cellular phones.

An industry-funded body known as the Wireless Technology Research Group (WTRG) is now planning its own experiments. The WTRG's chairman, George L. Carlo, says he is "quite impressed" by Lai's theoretical framework. He maintains, though, that animals exposed to peak microwave levels in Lai's microwave experiments might have heard a distracting noise from the equipment that could have influenced their subsequent learning. The organization, which Carlo says is scientifically independent, is already attempting to reproduce Lai's finding of DNA damage.

H. Keith Florig of Carnegie Mellon University, an engineer and expert on the effects of electromagnetic fields on cells, declares Lai "is a reputable scientist" who has won grants from the National Institutes of Health. Another expert, Frank Barnes of the University of Colorado, concurs. "There is a lot of evidence going around that shows something is going on" that could allow low-intensity microwaves to affect the brain, Barnes observes. But he notes that nobody has demonstrated any harmful effects and that the science is complex.

Intrigued by Lai's behavioral results, Zenon J. Sienkiewicz of Britain's National Radiological Protection Board—which is a major player in a European Commission study on the safety of microwaves—decided to check whether he, too, could detect an effect of fields on learning. To start with, Sienkiewicz exposed mice to power-line-frequency magnetic fields of 50 hertz. In a paper submitted to *Bioelectromagnetics*, Sienkiewicz reports that in four separate experiments using a multiarm maze, "exposure significantly reduced the rate of acquisition of the task," although the exposed mice did catch up eventually. The fields he studied were stronger than those found in homes. But inspired by the results with Lai's test, Sienkiewicz is now planning experiments with microwave-frequency fields.

In the U.S. the NRC reported earlier this year that there is "convincing evidence" that animals can respond behaviorally to electromagnetic fields, albeit ones stronger than those found domestically. Federal agencies are waiting for the results of the WTRG studies before deciding whether regulation is warranted. Carlo predicts the results will start to be published early next year. But at least one company is not waiting for answers. Hagenuk in Kiel, Germany, started advertising "low-radiation" cellular phones in Europe this past summer.

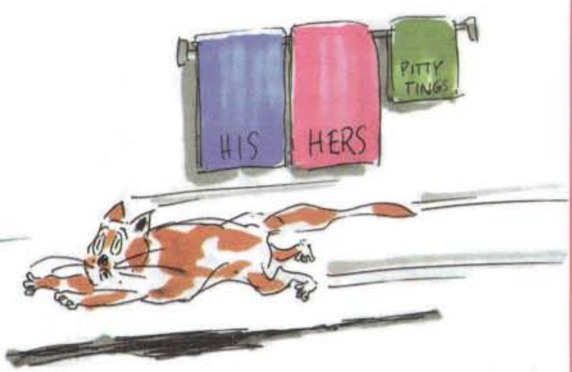
—Tim Beardsley in Washington, D.C.

ANTI GRAVITY

Full of Sound and Furry

Cats, it has long been held, have nine lives. Some six million Americans, with but one life, unfortunately have it made miserable by allergies to cats. Two thirds of these red-eyed, sniffling mouth-breathers share a survival strategy with small rodents—stay away from cats. The others, however, have decided that a feline-free existence would be catastrophic. Now comes a study showing the efficacy of a measure that might decrease respiratory distress, but with peril to the rest of the body: cat washing.

"Prior to our study there was some controversy in the literature regarding whether cat washing actually had any beneficial effects," notes study coauthor Judith Woodfolk of the University of Virginia Asthma and Allergic Diseases Center. In what probably looked like some kind of medieval witch trial, Woodfolk and her colleagues dunked a bunch of cats. In a more modern sequela to said dunking, they published their findings in a recent issue of the *Journal of Allergy and Clinical Immunology.*



Actually, the cats were not dunked, per se. One group was washed weekly by being immersed up to the neck for three minutes, then toweled off and left to dry. The (plain) water was a toasty 38 degrees Celsius. A second group was given an additional three-minute rinse in a second tub of clean water. Finally, a third group was washed weakly, with soap and warm water from a hose for about a minute.

The motivation behind soaking these cats was curiosity as to whether washing could decrease the levels, both on the cat and in the room air, of the major bad guy for cat-allergy sufferers, a protein called Fel d 1. (Its name comes from its being the first domestic feline allergen to be isolated and chemically characterized.) Contrary to a widely held notion, most of the allergen originates from the sebaceous glands in the cats' skin, not from the saliva. Washing removed significant amounts of Fel d 1 on the cats, which caused the airborne levels to plummet. Hosing lowered airborne allergen levels by 44 percent in a measurement taken three hours after the wash. Total immersion reduced it by an average of 79 percent, and the total dunk followed by rinsing brought the decrease to 84 percent.

Two problems, however, keep this cat tale from having a perfectly happy ending. One impediment is that allergen levels shot right back up within a week. Cat baths would thus need to be a regular habit. Which brings us to perhaps a bigger drawback than wash, rinse, repeat ad infinitum: cats, even declawed cats, have exceptionally sharp teeth.

"That's the question here," Woodfolk acknowledges. "How compliant is the animal going to be, regardless of the patient's compliance? From our experience, most of the cats actually became accustomed to the water. But they didn't particularly like it." Larry Kutner, who is a child-behavior columnist for *Parents* magazine and an allergy sufferer, has been washing two cats at regular intervals for some time. "I have yet to find one that enjoys it," he remarked purposefully.

Thomas Platts-Mills, lead author of the study, notes that those cat lovers who are both asthmatic and allergic have a potentially serious problem that must be carefully managed. "We need a method of helping patients, other than simply giving them more medicine," he says. "And washing cats, together with air filtration and decreasing carpets within the house, is a useful approach. Clearly, the decision about how much to do is in the hands of the patients."

With patience, and plenty of kitty treats, you can probably Pavlov your cat into at least tolerating the water. Which could keep the cats in the hands of the patients as well. *—Steve Mirsky*

MICHAEL CRAWFORD

Bringing Up Baby (in 3-D)

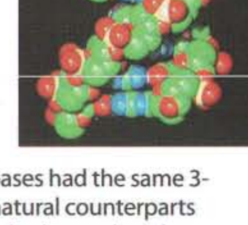
Researchers at Emory University have discovered by chance that a range of disorders involving three-dimensional vision are developmental in origin. Eye doctors long thought such deficits were genetic because they appeared in children born with cataracts. But when Ron Boothe and his colleagues induced cataracts in rhesus monkeys, none of these 3-D defects arose in infants older than three weeks. Further study showed that the monkeys' brains underwent a major reorganization after three weeks, prompted by environmental stimuli. This reorganization, which occurs at three months in humans, is essential for developing normal depth perception.

Brighter Sunshiny Days

Piecing together data from three satellites, Richard C. Willson of Columbia University reports that the sun may well be getting brighter. Indeed, the total solar irradiance—or the radiant power absorbed by the earth—rose 0.036 percent between 1986 and 1996, spanning one cycle of sunspot activity. If the sun steadily grows more luminous at this rate, Willson predicts that it will warm the globe by about 0.4 degree Celsius in the next century. In comparison, greenhouse gases are expected to heat the planet by about two degrees C in the next 50 to 100 years.

ATCG Puzzle Pieces

Biochemists have long held that weak hydrogen bonds let DNA strands pull apart and zip back together in just the right combinations: adenine molecules pair up with thymine, and cytosine seeks guanine. But Eric Kool of the University of Rochester recently proved that idea wrong. Kool found that geometry—and not hydrogen bonding—ensures accurate replication. To prove it, he made molecules resembling adenine and thymine. These fake bases had the same 3-D shapes as their natural counterparts but could not form hydrogen bonds. Even so, the artificial bases snapped into place as readily—and correctly—as the natural ones during replication.



LEONARD LESSIN *Peter Arnold, Inc.*

More "In Brief" on page 18

In Brief, continued from page 17

Mr. McGregor's Revenge

Farmers in New Zealand have set out to rid themselves of crop-eating rabbits once and for all: many are spreading liquefied livers from calicivirus-infected animals over carrots and oats left out as bait. The calicivirus, which has killed countless rabbits on the South Island so far, is used as a biological-control agent in Australia. But in New Zealand the government has banned it. Anyone found guilty of importing calicivirus to New Zealand could face five years in prison and a NZ$100,000 fine.

MICKEY GIBSON *Animals Animals*

Evaluation Evaluations

How accurate are student evaluations of instructors? Many university administrators value them enough to consult them in making tenure and pay decisions. But a new study shows that students give the highest marks to the most enthusiastic—and not necessarily the best—teachers. Stephen J. Ceci of Cornell University taught developmental psychology twice one year. In the fall, he gave his lectures as he had for the past two decades. In the spring, he did the same but changed the pitch in his voice and used more gestures. Second-semester students found Ceci not only more knowledgeable and tolerant but more fair, organized and accessible. And they claimed to have learned more, even though they did no better than first-semester students on the same exams.

Jet Chemistry

To cause a chemical reaction, you need heat, light, radiation, ultrasound or, as Kenneth S. Suslick and his students at the University of Illinois have shown, liquid jets. The scientists drove high-energy reactions and broke superstrong bonds by colliding two streams at a combined speed of 450 miles per hour. Water jets, they found, generated hydrogen peroxide and fragments capable of destroying chlorocarbon compounds. For this reason, Suslick suggests that liquid jets might offer a simple way to purify water supplies containing low levels of chemical waste. *—Kristin Leutwyler*

ENVIRONMENT

SMOKE ALARM

Haze from fires might promote bacterial growth

This past September, choking smoke from unchecked forest fires blanketed millions of square miles in southeast Asia. But that was not the only part of the world where burning of vegetation caused widespread haze. In the Amazon Basin the 1997 burning season produced a "very thick" pall that extended far beyond the region where smoke has spread in recent years, according to Paulo Artaxo of the University of São Paulo. Forrest M. Mims III, an independent scientist who runs the Sun Photometer Atmospheric Network and is based in Seguin, Tex., says smoke may have covered half of Brazil when he was in the country in August. The blockage of sunlight, Mims believes, may encourage the spread of harmful bacteria and viruses.

Many of the fires in Brazil are set to clear the rain forest, although some take hold accidentally when farmers burn pasture, Artaxo states. One reason the 1997 fires were so extensive is that forests were very dry, a consequence of El Niño, a periodic climatic oscillation, which is quite strong this year.

The health effects of breathing smog from July to October each year are unknown. Yet the clues seem ominous: the most polluted U.S. cities, for example, generally have higher death rates than others. And Mims reports that physicians in the remote city of Alta Floresta in west-central Brazil concluded that half the local population was suffering from respiratory illness. In Manaus, some 600 miles northwest, there were "very significant" increases in the number of patients hospitalized with bronchitis, Artaxo notes.

Mims suggests that one way smog might cause illness is by absorbing ultraviolet light, specifically the band known as UV-B, because it is well known to kill bacteria and viruses. Mims found that levels of UV-B in Alta Floresta during one of the smokiest days of his stay were less than a tenth of levels on a clear day. Sometimes measured UV-B reached zero. Light that plants use for photosynthesis was reduced by more than 50 percent on some days. Mims also found that on reduced UV-B days, airborne bacteria that lack internal pigmentation became more common relative to pigmented types. Because most pathogens are nonpigmented (for reasons that are unclear), Mims thinks bacteria and viruses could become more of a health threat in hazy conditions.

Further research will be needed to evaluate Mims's findings, which he was expecting to submit for formal publication soon. Yet research on the Amazon pall is not proceeding as quickly as many scientists would like. Although the capabilities of satellites are improving, monitoring of biomass burning "is not adequate," says Brent N. Holben of the

HANS W. SILVESTER/RAPHO *Liaison International*

***RAIN FOREST BURNS** in the Amazon basin. Unusually dry conditions caused large conflagrations that blanketed much of Brazil during this past year's fire season.*

National Aeronautics and Space Administration Goddard Space Flight Center.

Bureaucratic delays appear to be part of the problem. Two years ago NASA told Holben to remove from Brazil a network of ground-based instruments that could validate satellite measurements, because officials had concluded that Brazil and the U.S. needed a formal agreement covering the network. No agreement has been forthcoming, and Holben is still waiting to take his instruments back to Brazil.

—Tim Beardsley in Washington, D.C.

ASTRONOMY

SLAYING THE "AGE PARADOX"

Is the universe now old enough for its stars?

The universe is younger than some of its offspring, astrophysicists whispered last year. Born a mere nine to 12 billion years ago, it contains aging clumps of stars called globular clusters that looked to be 16 to 18 billion years old. This year a drum roll of press releases is declaring that the "age paradox" has been vanquished. Researchers analyzing data from the European Space Agency's Hipparcos satellite, the announcements claim, have shown that globular clusters may be only nine or 10 billion years old.

Some observers, on the other hand, aren't so quick to pronounce the age paradox as solved. Rather they are suggesting that Hipparcos's most profound result is to show that scientists don't understand stars very well at all.

Launched in 1989, the satellite had the unassuming task of measuring the luminosities and positions of some million stars using the ancient technique of parallax. It looked at the celestial sphere from two opposite points of the earth's orbit around the sun, in effect endowing its human operators with eyes spaced 186 million miles apart. The resulting three-dimensional view of the sky revealed the distances to individual stars with unprecedented precision.

The leap from Hipparcos's data to the age of a globular cluster is, however, one of much faith. The clusters roam the Milky Way's halo, the nebulous regions outside the galaxy's disk, and are too far away for parallax measurements. So astrophysicists used Hipparcos's precise measurements of distance and brightness of other stars such as subdwarfs—dim objects lacking metals and other heavy elements—and compared them with compositionally similar stars in globular clusters. If the subdwarfs happen to be younger siblings of their lookalikes in the clusters, the intrinsic brightness of the latter stars can be deduced using models of stellar evolution.

By such methods, many theorists calculate that the clusters are brighter than earlier believed. More brilliant stars burn up their fuel and age faster, so the globular clusters must be quite young—the numbers now range anywhere from nine to 15 billion years old.

Catherine Turon of the Paris-Meudon Observatory, who along with others calculates 12.8 to 15.2 billion years for the age of a particular cluster, M92, admits to theoretical uncertainties. There is difficulty in getting models adapted to such extreme objects with low metallicity, she explains. The only reference point for theorists is the sun, a middle-aged star rich in heavy elements, much different from the subdwarfs used in several of the comparisons. Processes not currently accounted for—such as fast rotation or the metals having sunk out of view into the subdwarf's center—could be skewing the conclusions.

One of the more cautious is the European Space Agency's Michael Perryman, project scientist for Hipparcos. "I would be reluctant to accept any of these results as the final word," he declares. "There's too much massaging to get things to fit." None of the models, he says, accurately explain all the observed properties of stars and thus do not inspire great confidence. Worse, Hipparcos data have shown that some stellar models—including those that seemingly encompass the sun—are spectacularly wrong.

The distance to the sunlike stars in the Pleiades, for instance, has been revised from 424 to 378 light-years, indicating that they are an astonishing 30 percent dimmer than the sun. "We don't yet understand where [the faintness] comes from," muses Floor van Leeuwen of the Royal Greenwich Observatory in Cambridge. "And therefore it has not entered as a parameter in models used to determine the ages of clusters."

Extrapolating the models to globular clusters builds on this shaky ground, so that the ages deduced by comparing kinds of stars—Cepheids, RR Lyraes and red giants, in addition to subdwarfs—contradict one another. "People tend to dismiss easily results of others that don't fit their own," van Leeuwen says. "My feeling is that it all adds up to a lot of uncertainty." As much as 40 percent, he guesses.

Such levels of systematic errors imply that the age paradox still has some life left. To kill it for good—which they will some day—astronomers need first to grasp the excruciatingly complex processes occurring inside a variety of stars. As Perryman puts it, "Watch this space."

—Madhusree Mukerjee

TONY AND DAPHNE HALLAS *Astro Photo*

THE PLEIADES
are 30 percent fainter than expected, the Hipparcos satellite finds. The measurement casts doubt on current models of stars.

BY THE NUMBERS

Freshwater Fish at Risk in the U.S.

Of all places on earth, rivers and lakes are the most dangerous for wildlife. Their natural ecology is segmented by dams and locks, their waters are diverted, and they are the principal depositories of civilization's wastes. It is therefore not surprising that aquatic species in the U.S. are at far greater risk of extinction than mammals and birds are. Of the 822 fish species native to American rivers and lakes, as many as 21 have become extinct since the time of the first European settlement, according to the Nature Conservancy in Arlington, Va., and its partners in the Natural Heritage Network. Their data show that another 297 species—36 percent of the total—are currently at risk of extinction. Other freshwater animals are in an even more perilous condition: 38 percent of amphibian, 50 percent of crayfish and 56 percent of mussel species are in jeopardy. Another 12 percent of mussel species are already extinct.

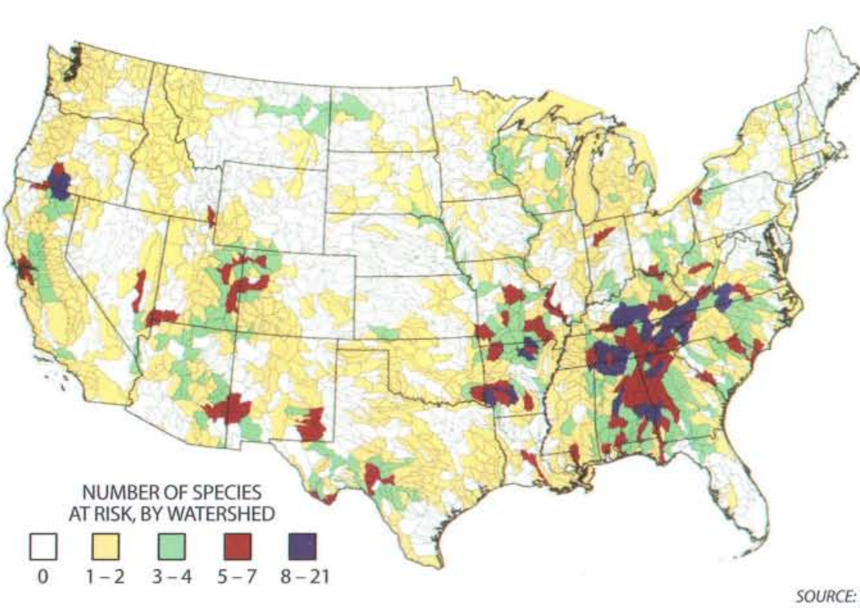
The three most important threats to freshwater fauna are agricultural runoff, dams and water diversion, and interference from exotic species (such as the flathead catfish, which was introduced in the Southwest and many other places for recreational fishing). Such alien species compete with native species and generally upset the balance of local ecologies.

Within the U.S. there is a wide variation in the status of fish, with the southern half of the country having far more imperiled species than the northern half; the large map below shows the number at risk in the 2,111 watersheds of the lower 48 states. The area of greatest concern is the Southeast, particularly the region stretching from Alabama and Georgia through Tennessee and Kentucky into southwest Virginia. This region is extraordinarily bountiful (*map at lower left*), rivaling the waters of tropical rain forests in the variety of its freshwater fauna. The large number of species throughout the Southeast stems from the highly diverse range of its ecosystems, including the Appalachian Mountains, the Appalachian Plateau, the Piedmont and the coastal plain. Also, this region, unlike the North, did not suffer the devastating effects of Pleistocene glaciation. Risk rates are higher in the Southeast than in the North (*map at lower right*) largely because of the effect that water projects have on the many localized fish species.

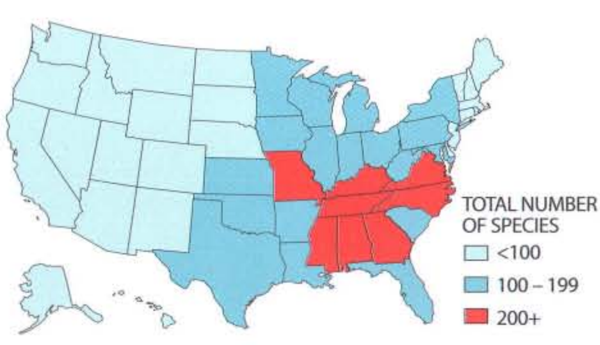
A second area of concern is the Southwest. This largely arid region, which has far fewer native freshwater fish species than the eastern part of the country, has been more severely affected by introduced species and water diversions. The result has been some of the highest risk rates recorded. In California, 42 percent of the 67 native fish species are at risk, and in Arizona the rate is an astonishing 63 percent.

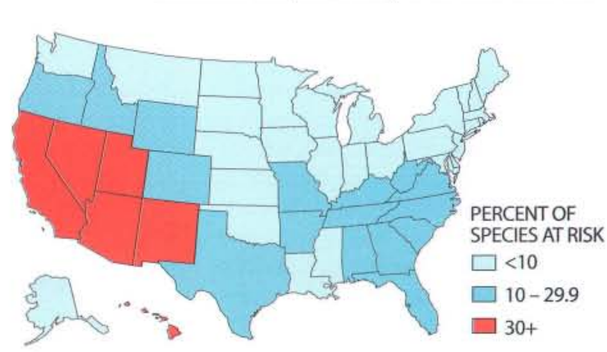
Another contributor to the high rates in some western states, such as California and Nevada, is the large number of species that have a limited range of habitat. An example is the desert pupfish, which is restricted to isolated and often vulnerable desert springs. Species with limited ranges also account for the high numbers of fish species at risk in the Ozark Plateau of northern Arkansas and southern Missouri and in the Klamath region of northern California and southern Oregon.

—Rodger Doyle (rdoyle2@aol.com)



SOURCE: The Nature Conservancy and Natural Heritage Network in cooperation with the Association for Biodiversity Information. All data are from 1997; excluded are species not native to their areas.





RODGER DOYLE

PROFILE

Molding the Web

Its inventor, Tim Berners-Lee, says the World Wide Web hasn't nearly reached its potential

The intense Tim Berners-Lee abruptly rolls his chair away from the central table in his bare corner office over to two huge computer screens and starts typing as fast as he is speaking—for the listener, it is akin to a thick hailstorm hitting. The inventor of the World Wide Web is about to demonstrate how he first envisioned his creation and, by extension, how it has not lived up to his expectations.

With amazing speed, Berners-Lee uses his original software to set up a home page, make links to new pages and toggle between them. He shows how easy it should be to insert connections to other Web sites and how any user should be able to save comments into a document—just like writing in the margin of your book, but in this case, your note could transport you to the electronic version of the place you are musing about. "It was to be a very interactive medium; that was the idea. But you ain't got that," Berners-Lee laments.

The disappointment fizzles in a second, though, and Berners-Lee's freewheeling, high-velocity, superhyperlinked brain—the ur-Web itself—returns to thoughts of what the World Wide Web will become. He speaks almost reverently. No matter how many interviews the seemingly shy Berners-Lee agrees to, no matter how often he is asked to give a "vision" talk, no matter how hard he tries to speak slowly, there is a point at which the 42-year-old British physicist cannot contain his enthusiasm. In his world, the Web can empower people and transform society by allowing everyone self-expression and access to all information. "The Web can help people to understand the way that others live and love and are human, to understand the humanity of people," Berners-Lee expounds, almost tripping over his words.

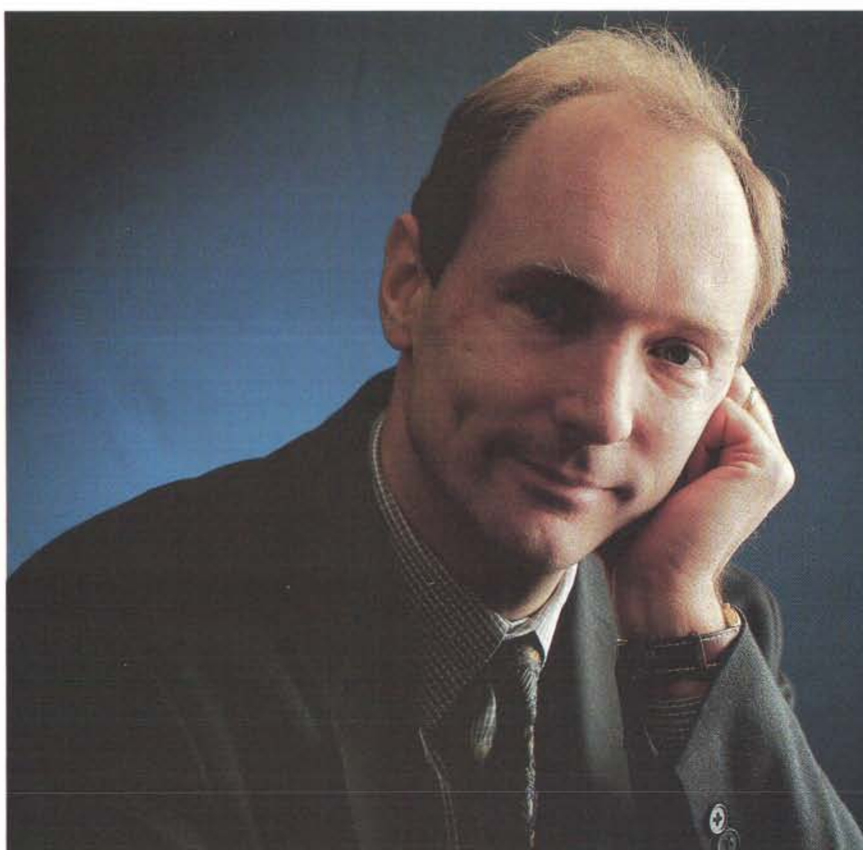
Berners-Lee has been shaping the evolution of this electronic extravaganza from a nexus of quiet, grayish offices in a nondescript building at the Massachusetts Institute of Technology. There Berners-Lee directs the World Wide Web Consortium, or W3C, as it is called. Composed of some 40 staff people scattered around the world and 217 members, including fiercely competing communications and computer companies, the consortium serves as a standards organization for the Web. Just as the Internet Society establishes protocols so that the Internet retains its "inter-ness," W3C tries to ensure that no matter what commercial developments unfold, all the Web's strands remain interwoven.

With his ruffled blond hair and modest manner, Berners-Lee hardly looks like the one person who can get dueling giants Microsoft and Netscape to, if not kiss and make up, at least sit in a room together. Yet every issue arising around and about the Web—from how fast networks can transmit information to how to contend with cyberporn, the threat of censorship and the challenges of safe electronic commerce—is being responded to and molded by the largely hidden hands of Berners-Lee.

It is somewhat hard to plumb the origins of Berners-Lee's global humanism, because he is as protective of his privacy as he is of the integrity of the Web. He declines to answer questions about his wife or his two young children, although a picture of the towheaded youngsters is the only decoration in his office.

Timothy J. Berners-Lee was born and raised in London. His parents, Conway and Mary Berners-Lee, are mathematicians, and both worked on England's first commercial computer in the 1950s, the Ferranti Mark 1. The Berners-Lees occasionally discussed imaginary numbers at mealtime; as a child Tim constructed a Ferranti replica, complete with clock and punch cards, out of cardboard boxes. According to a former colleague, the family was also respectful of spiders: Mary Berners-Lee hung cotton threads down into the bathtub so fallen spiders could scale the smooth sides.

Berners-Lee says he had a Protestant upbringing but rejected literal Christianity as a teenager because it was incom-



SAM OGDEN

FORGOING WEALTH, Berners-Lee has chosen to protect the integrity of the Web.

patible with science. He now describes himself as a Unitarian Universalist. "It tackles the spiritual side of people's lives and of values and of the things you need to live your life, but it doesn't require you to believe six impossible things before breakfast," he says wryly.

Berners-Lee graduated in 1976 with first-class honors in theoretical physics from the Queen's College at the University of Oxford. In 1980, after various software-writing jobs, he spent six months at CERN, the European laboratory for particle physics near Geneva, where he designed a calendar program called Enquire to keep track of his own random associations; it later became the basis for the Web. He returned to CERN in 1984 as a software engineer.

The rest is ancient Web history. Berners-Lee wanted to create a means for far-flung researchers to share one another's data and work easily together. So, in 1990, he wrote specifications for HTML (hypertext markup language), HTTP (hypertext transfer protocol) and the precursor of URL (uniform resource locator). The idea of hypertext had been bandied about for a long time. In 1945 Vannevar Bush described the Memex machine, a microfilm-based system that could link associated information or ideas through "trails." Then, in 1965, Theodor H. Nelson, a software designer and writer, aphorized the term "hypertext." Yet no one made it happen. "We had been talking about Web-like things for 20 years in the industry," notes Eric Schmidt of Novell. "Why didn't we invent it?"

The answer may be found by following Berners-Lee's conversation. "He speaks in hyperlinks," notes W3C colleague Sally Khudairi, no sluggish talker herself. She keeps a bottle of aspirin handy for the days when she can't keep up with her boss.

Berners-Lee and his CERN compatriot Robert Cailliau put the free Web software on the Internet in 1991. It didn't take off until 1993, when Marc Andreessen and his colleagues at the University of Illinois, who had seen one of the early Web browsers called ViolaWWW, wrote the now famous Mosaic. Between 1991 and 1994 the number of Web clients grew from about 10 to 100,000. As a research facility, CERN was not the right place for such a fast-moving enterprise. "People started saying, 'Look, this thing is becoming so big that our company is completely orienting itself around the Web. We want to know that it will be stable.' They wanted to know that there will be something keeping it together," Berners-Lee recounts, explaining the birth of W3C, his ever present energy revealed in quick blasts of movement—arms crossed suddenly here, chair lowered quickly there, chin in hand for a moment, a short laugh.

Although the hub of the Web, the offices of W3C are surprisingly quiet. The carpeted hallways are usually empty; doors are pulled shut. The staff lives on the computer, the telephone or the road—working at all hours to endow the Web with whatever technological standards, civility and ethics it maintains. Berners-Lee's egalitarianism informs the modus operandi of the consortium.

Each firm belonging to W3C signs a contract giving Berners-Lee the final say in specifications for the Web. In the three years since W3C was founded, however, Berners-Lee has never ruled by fiat. "Tim doesn't work that way," says Carl Cargill of Netscape. "Tim leads by his vision. And if you disagree with his vision, he will talk to you and talk to you until he agrees with your vision or you agree with his—or both of you come to a new vision." This process is crucial because W3C exists through consensus.


SAM OGDEN

W3C STAFF
ensures the Web stays Web-like.

Making sure every Web user and creator can experience exactly the same thing is integral to Berners-Lee's goal of "interoperability." The term simply means that the Web needs to be a system in which everyone, no matter their equipment or software, can participate equally. Interoperability, of course, is the nemesis of the commercial world: witness the tags on sites that say they are best viewed by a particular browser.

"It is important to realize that the Web is what we make it. 'We' being the people who read, the people who teach children how to surf the Web, the people who put information up on the Web. Particularly the people who make links," continues Berners-Lee, picking up speed, as he does whenever he talks about the philosophical underpinnings of the Web. "You should write and read what you believe in. And if you keep doing that, then you will create a Web that is one of value. If other people read it, then your ideas spread. But that is not a prerequisite. The Web doesn't force anything down your throat. If you are worried that your children are going to read low-quality information, teach them. Teach them what to read. Teach them how to judge information."

Receiving a piece of this vision directly from Berners-Lee is a rare commodity as W3C grows. Even though they are black-belt Webmasters, W3C team members can have a hard time communicating clearly about how to proceed on a topic or how to respond to a crisis with a company. The vision can also erode under constant conversations with company engineers or executives whose interests lie purely in code or markets. "We on the staff have a real need for him to project his vision," Dan Connolly says of W3C. "Some days it seems very important to remember: Should I do what the companies want to do or what is good for the Web?" Connolly adds that certain staffers wish for Berners-Lee to become rather "bold and unapologetic" so that W3C can accomplish its mission—"To realize the full potential of the Web"—with less industry wrestling.

Even as he says it, Connolly knows it is not going to happen. Berners-Lee could have made millions by taking his skills to the private sector; he could be ruling W3C with an iron fist; he could be collapsing his vision under the weight of commercialism; he could find a soapbox. But then he would not be the man who invented the Web.

Although he has neither favorite sites nor time to browse, Berners-Lee says he does use the Web to buy gifts. He even ordered his parents a case of wine for Christmas, expecting that it would be delivered by the local British supermarket—as explained on the Web site. "It ended up being delivered, at what must have been incredible cost, by taxi—all the way across the country," Berners-Lee laughs. The driver finally arrived in the middle of the night with what he must have thought was an emergency delivery. "I have never found out the story," Berners-Lee giggles. "I only paid £7, that's just $10, for delivery."

—Marguerite Holloway

ROAD WARRIORS

Technology and Business reports on contests demonstrating extreme ways of powering wheeled vehicles: one with jet engines, the other with gravity.

SHOCK-WAVE SHOWDOWN IN THE OLD WEST

British car and driver break the sound barrier

Nevada's Black Rock Desert has become a staging ground for the type of event that would have difficulty finding a home anywhere else on the planet. This vast, dry lake bed—a stretch of flatness that seems to extend to infinity—attracts amateur rocketeers who claim to have launched a home-built projectile into space. Aging hippies and computer freaks have taken off their clothes here during the annual Burning Man Festival, which culminates in the torching of a 40-foot-high effigy. But the most extreme act to have occurred in these unending reaches took place in September and October, when British and American drivers launched separate attempts to punch through the sound barrier while keeping four wheels in contact with the earth.

As of mid-October, this friendly competition had turned into a triumph for the highly regimented British contingent—some of whom had taken leave from jobs in the Royal Air Force to lodge themselves in this dusty corner of the Old West. On October 15, almost exactly 50 years after American Chuck Yeager broke the sound barrier, the British driver went supersonic in a car. Andy Green, an RAF fighter pilot in his real job, drove *Thrust SSC*—the 10-ton jetmobile powered by two Rolls-Royce Spey jet engines—to a new land-speed record of 763.035 miles per hour. The sound barrier, which varies with temperature, measured about 750 mph during Green's record-setting runs.

The supersonic milestone broke Green's own record of 714.144 mph, set three weeks before. And Green did so two days after two earlier jaunts down the 13-mile course that also ripped through the sonic barrier, but which missed a record by a minute. To achieve a record, the International Automobile Federation requires two runs through a measured mile in opposite directions within one hour of each other.

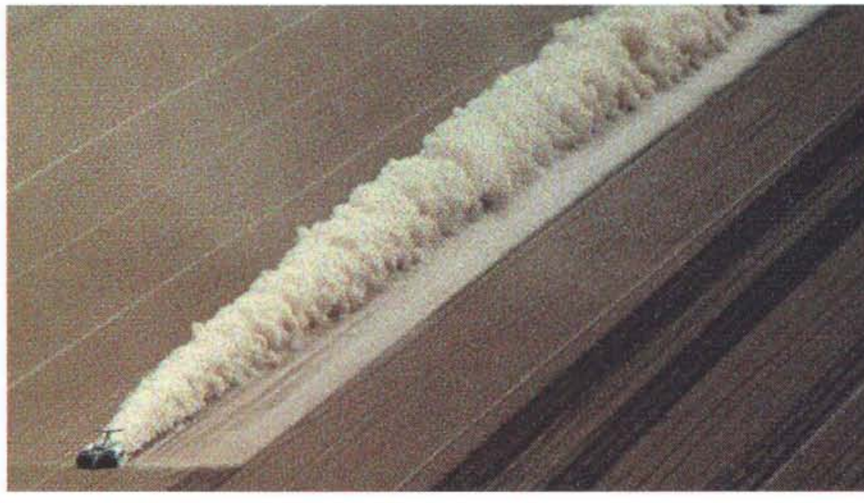
During his stay at Black Rock, the tall, iron-confident Oxford graduate–cum–fighter ace had also smashed the previous land-speed record of 633 mph set in 1983 at Black Rock. That earlier mark was held by the man who had recruited Green. Richard Noble had decided against driving the car while devoting himself to the enormous logistical difficulties entailed in building *Thrust SSC* and financing this private, 30-member British expeditionary force. Noble and Green's labors produced a remarkable spectacle for any visitor to this remote desert outpost. Spectators heard sonic booms and could see evidence of the supersonic shock waves. Buildings were reported to have shaken in Gerlach, a town some 12 miles distant. The neck-craning speed and the cloud of dust shooting from behind the car recalled a guided missile spewing rocket exhaust while traveling in a horizontal trajectory.

The man who had repeatedly risked his life, meanwhile, displayed a dispassionately analytical attitude about the experience of driving a land-hugging car at a velocity higher than any commercial airliner but the Concorde. "It's just like a fast jet, but less maneuverable around corners," Green says of his 110,000-horsepower monster.

The American competitors, headed by Craig Breedlove, the five-time land-speed record holder, fared less well. The team and the sleekly elegant *Spirit of America* were still recovering from the world's highest-land-speed accident. In the fall of 1996 Breedlove survived when one of the rear wheels of his vehicle left the ground at Black Rock at about 675 mph. The *Spirit of America* veered into a U-turn that barely missed a spectator's vehicle stationed on the alkaline desert basin, known as a playa.

After the accident, Breedlove and his crew rebuilt the heavily damaged single-engine jet car. But when it arrived at Black Rock in early September, it confronted a series of mechanical problems, including a damaged engine, front-wheel instability, faulty readings from onboard sensors and the need to replace some of the tires and wheels. As of mid-October, the car had reached an unofficial top speed of 636 mph. Still, Breedlove vowed to beat the British eventually.

Appropriately, this head-to-head showdown occurred in a corner of northern Nevada that retains much of its frontier character. The nearest town, Gerlach, is but a few miles from a path, sometimes called the Death Route, that took thousands of settlers across Black Rock's forbidding barrenness on their way to Oregon and California. Today



MARILYN NEWTON

EFFECT OF SHOCK WAVE can be seen in the lateral stream of dust stretching to the side of Thrust SSC.

this hamlet of 350 residents, nestled at an altitude of nearly 4,000 feet, has five bars but no grocery store.

By early October, Gerlach's licensed establishments had succumbed thoroughly to the throes of supersonic fever. The Black Rock Salloon [*sic*]—the main after-hours gathering place for both teams—featured a lighted sign in the parking lot that supplied the highest speed attained by both the *Spirit of America* and *Thrust SSC*. And just outside of town on the way to the playa, someone had spray-painted "850," as in miles per hour, over the often ignored 55-mph speed-limit sign.

More than anything, the race to the terrestrial sound barrier showed that this level of record setting can no longer be accomplished by mere tinkerers. Organizing the *Thrust* team amounted to staging the equivalent of a small-scale military campaign, replete with a huge Russian cargo transport to deliver the car to Reno-Tahoe International Airport. *Thrust SSC* also proved a technical marvel. It incorporated an active suspension that changed how loads were distributed on the front and rear as it neared Mach 1. And the underside of the machine was fitted with technology adapted from supersonic wind tunnels that prevented shock waves from moving about and causing structural damage to the vehicle.

Funds for the 250,000 gallons of fuel for the Antonov air cargo jet's journey to Nevada came from donations from team supporters, some of whose contributions were solicited on the Internet. One commentator in Gerlach on the changing nature of these events was Art Arfons, who raced against Breedlove on the Bonneville Salt Flats in the 1960s for the title of fastest man on earth. After observing the preparations of the British, the 71-year-old Ohioan, who still resembles a hot rodder in his wraparound sunglasses, could only express amazement. "A backyard mechanic could never do this anymore," Arfons said. "This has turned into a high-tech business."

—Gary Stix at Black Rock Desert, Nev.

NEWTON 1, EINSTEIN 0

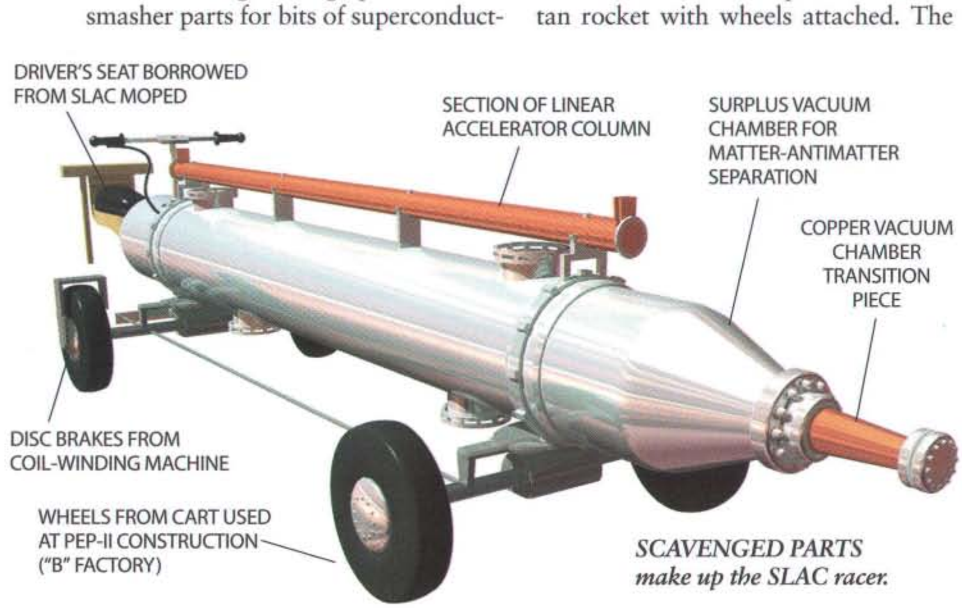
High-energy physicists enter a soapbox derby—and lose

Particle physicists may not be the most solemn variety of scientist—they did come up with "charmed" quarks, after all—but they are rarely seen clowning around, at least in broad daylight. So when the Stanford Linear Accelerator Center recently asked SCIENTIFIC AMERICAN to put up $1,000 so it could enter a soapbox derby to benefit the local Peninsula Community Foundation to combat teenage alcohol abuse (SLAC is barred from spending its federal funding on such events), the prospect was too intriguing to pass up.

Off they went, we imagined, to huddle over supercomputers calculating the optimal design from first principles, then to scavenge through piles of atom-smasher parts for bits of superconducting alloy and positron-transmutated whosiwhatsits. Surely such intellectual horsepower could not fail to assemble the detritus of a multimillion-dollar technological marvel into a winning race car.

Imagine my surprise, then, when wandering through the crowd milling this September morning at the race site on Sand Hill Road, a gentle incline that rises from Stanford University past SLAC and numerous venture-capital firms that own substantial chunks of Silicon Valley, I happen on the SLAC pit and find no breakthrough in fluid dynamics, no clever use of Earth's magnetism to assist gravity, but a behemoth.

A high-tech behemoth, granted. One that looks a bit like a quarter-scale Titan rocket with wheels attached. The main fuselage, explains Ossie Millican, who runs SLAC's machine shop and supervised the vehicle's construction, is a vacuum chamber of the kind used to separate matter from antimatter. This particular tank was a prototype and so never saw any action, Millican assures me, adding that "we ran a Geiger counter over it several times just to be sure."



SCAVENGED PARTS make up the SLAC racer.

BRYAN CHRISTIE

But what really has passersby doing double takes is an extra part that the other 34 cars lack: an accelerator. Not the pedal type, mind you—all these racers are powered by gravity alone—but the particle type, the kind that kicks electrons nearly to light speed, then smashes them into antielectrons to create showers of subatomic particles so exotic you'd have to hang around a black hole or a big bang to see them in the wild. This is just a section of the accelerator, of course; no electromagnets or antimatter here. But with a blinking, battery-powered LED mounted where the beam would go, it certainly looks cool.

That, evidently, was the goal. "We're not going for speed," Millican says, a touch defensively. "We're relying on a non-Newtonian exemption to win."

As the team heaves the 1,445-pound racer, dubbed the Z-Mobile, up to the starting line for its heat, SLAC engineer Eric Bong wriggles into his motorcycle leathers and mounts the monster. "Usually we're looking for high-energy collisions, but not this time," he quips.

Down at the finish line, the emcee is raising the crowd's expectations. "The SLAC entry cost at least a million bucks," he deadpans. But wait: rolling into lane two is the competition, a boxy car sponsored by a legal firm, the Venture Law Group, and made primarily

EDWARD CALDWELL

Z-MOBILE gets ready to roll.

out of what appears to be stale foccacia bread. Could be pretzel dough.

As the starter raises his pistol, the SLAC team prepares to shove Bong and his buggy into motion, even though "test runs showed that pushing only made a one-mile-per-hour difference over not pushing," Millican laughs. There's the gun, and they're off. It's neck and neck for about six inches, until the lawyer pulls ahead and leaves Bong in a trail of bread crumbs. Radar guns clock the Z-Mobile at 26 miles per hour just before it crosses the finish line. By way of comparison, the winner of the event, which raised $102,000, was an extravagant teardrop-shaped speedster that hit 47 mph; the venture-capital firm Mohr, Davidow reportedly sunk $10,000 into it.

But those capitalists probably didn't have as much fun as the physicists. After all, Millican says, it's not every day you get "the opportunity to see so many ordinarily serious scientists with lopsided grins and the glint of bad '50s science-fiction movies in their eyes"—a glint that in Millican's case looks distinctly like an evil eye aimed at the bread car. "Next year," he glowers, "they're toast."

—W. Wayt Gibbs in Menlo Park, Calif.

SENSORS

X-RAY SOUND

A new device sounds out the contents of sealed containers

Here's a puzzle: You're handed an artillery shell filled with either ordinary explosive or deadly nerve gas. How do you determine what it contains without risking total nervous shutdown? The question is not as hypothetical as it may seem. United Nations inspectors enforcing the Chemical Weapons Convention Treaty face this problem all too often. Fortunately, they now have an answer: a device that when pressed against a container of almost any shape or size can identify its contents using sound. The technique, which has already spawned 12 patent applications, may have myriad industrial and environmental uses.

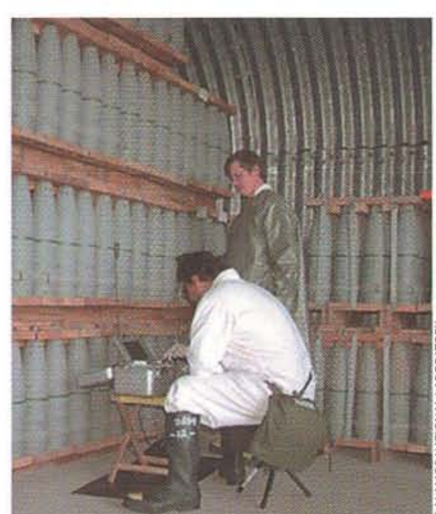
Dipen N. Sinha and his colleagues built the sensor at Los Alamos National Laboratory and described it at the American Chemical Society meeting in Las Vegas this past September. In about 20 seconds, Sinha claims, a soldier using the five-pound, battery-powered gadget can reliably distinguish not only whether a shell contains chemical weapons but also which of the wide variety of toxic cocktails it holds.

At first glance, the machine looks a bit like the ultrasound imagers used in hospitals. It has one piezoelectric pad that acts as a speaker and another that serves as a microphone. But unlike an imager, this sensor can determine the makeup of a hidden material. It does so by exploiting sound in a different way.

By using "swept frequency acoustic interferometry," to be precise. Those big words mask what are "actually extremely simple principles of physics that have been well understood since the 1940s," Sinha says. Toot a bugle, and its tubes vibrate at one set of frequencies, the air inside them at another. Pursing your lips just right creates standing waves that resonate inside the horn and emerge as musical notes. Sinha's sensor similarly listens for the resonant peaks emitted by an object as the speaker pumps sound waves into it at frequencies that rise gradually from one kilohertz to 15 megahertz. By analyzing the peaks and valleys and how they change as the frequency rises, Sinha's software calculates the density of the hidden material, the speed of sound through it and the material's ability to absorb tones of different pitches.

Scientists have long known how to do this kind of sonic analysis under controlled lab conditions, using calibrated vessels. "What we have done is to develop very efficient computer algorithms that can extract all this information from measurements of any container," Sinha elaborates.

"As experts, we all knew that what he set out to do was possible in principle, but we were amazed that he had actually succeeded in applying the fundamentals to such a variety of practical and messy problems," affirms Logan E. Hargrove of the Office of Naval Research. Chemical weapons identification is just a start: Sinha says his team has demonstrated that the technique can be used to monitor water inside tanks for pollution and to detect bacterial growth inside milk cartons and canned coffee. It might even come in handy in medicine. "We put this thing up to our heads



LOS ALAMOS NATIONAL LABORATORY

ACOUSTIC SENSOR distinguished chemical weapons from conventional artillery shells at the Deseret Chemical Depot in Tooele, Utah.

and were able to measure intercranial pressure in our brain cavities," he reports. "The only other way to do that is to drill a hole in the skull."

Los Alamos has already licensed its patents on the technology to several companies, Sinha says. Because the sensor can detect very small changes in chemical composition, he asserts, "people in the semiconductor industry are very interested in using it for quality control of cleaning fluids."

Sinha declines to name any potential partners, however, so it is not possible to confirm how widely useful the technique will be in actual industrial operations. "I got very excited when we were able to use this technique to distinguish Coke from Diet Coke," recalls Wolfgang H. Sachse, a physicist at Cornell University. "But then we were unable to distinguish Diet Coke from water. So I have mixed feelings about it."

"Sachse used a rather crude homemade instrument that does not have the requisite sensitivity," Sinha retorts. And in any case, Diet Coke doesn't detonate.

—W. Wayt Gibbs in Las Vegas

TOXIC CLEANUP

POLLUTION-PURGING POPLARS

Trees that break down organic contaminants

In 1984 a truck carrying a load of toxic solvent spun off an icy stretch of Interstate 5 in southernmost Oregon, near the town of Central Point. In moments, hundreds of gallons of 1,1,1-trichloroethane gushed over the ground; 13 years and multiple cleanup efforts later, the chemical still leaches from the soil, feeding a spreading pool of contaminated groundwater that infiltrates nearby drinking wells. Born in an instant, the spill could take decades of work to eliminate.

Now scientists led by Milton Gordon, Lee Newman and Stuart Strand of the University of Washington propose a sylvan solution: let trees treat the contamination. In May the team took the first step: it planted nearly 800 hybrid poplars in neat ranks downstream of the spill; the rest is simply wait and see.


DAVID J. BOYLE *Earth Scenes*

POPLAR TREES
could be hybridized into varieties that soak up and break down toxic organic compounds in soil.

This approach is known as phytoremediation. In the past several years researchers have tested the power of plants to scour toxic substances from earth and water; plants have proved effective at extracting heavy metals, including isotopes of uranium, cesium and strontium. Now experimenters are turning to trees to handle organic solvents.

Although data on the young poplars in Oregon will not be in for a while, there is reason to be optimistic. Gordon and his colleagues have been pitting poplars against pollutants in outdoor experiments in Fife, Wash., for the last three growing seasons. Seven days a week, from dawn to dusk, researchers feed 30-foot-tall potted plants a steady diet of organic solvents—mimicking the situation at chemical spills where contaminants travel in moving water.

Perhaps the most important of these toxic compounds is trichloroethylene (TCE), a dry-cleaning and degreasing solvent that is a suspected carcinogen and one of the most common contaminants in sites targeted by the Environmental Protection Agency's Superfund. In Fife, plots bearing trees have been removing more than 97 percent of the TCE piped in—and the numbers are improving with each season.

Gordon suspects two fates for TCE in his poplars. Some may be bound up in an inert form in the poplars' tissues, in which case the trees could be harvested and burned to destroy the chemical. The rest is broken down by the plant. Experiments conducted on poplar cells cultured in the laboratory indicate that the trees can use oxidative enzymes to metabolize TCE and other chlorinated organic compounds; the trees in Fife may be converting TCE all the way to normal metabolic end points such as carbon dioxide and salts. (That would mark a distinct change in phytoremediation efforts: for example, in heavy-metal extraction, plants simply store the toxic substance.)

If the poplars work well in the field, they should be especially useful for cleaning spills in densely populated areas. Unlike conventional mechanical pump-and-strip systems, the poplars do not release appreciable amounts of solvent into the air. Moreover, Strand says, "they're cheaper than the pump-and-treat operations that retain the chemical." Planting the trees involved little more than sinking foot-long cuttings—essentially sticks—into the ground.

Why choose poplars? "We knew we'd get a lot of biomass quickly," Gordon says. The hybrids at Fife, originally developed for the paper and pulp industry, can grow 15 feet a year. And the growing trees take up massive quantities of contaminated water—at the peak of last season each young tree treated at least 25 gallons a day. As for the productive poplar-TCE match, Gordon confesses, "We got lucky." Poplars were the first trees his group tested.

Gordon's team is leaving less to chance the next time. It is working toward genetically engineering poplars to handle other types of organic pollutants. And the group is searching for trees with inherent treatment potential better suited to different climates or chemicals; candidates include willow, black locust, Hawaiian koa, even eucalyptus. "It's important to get the right tree for the job," Newman remarks; if the lucky streak continues, more of these gentle giants will prove to be naturals.

—Mia Schmiedeskamp in Oregon

CYBER VIEW

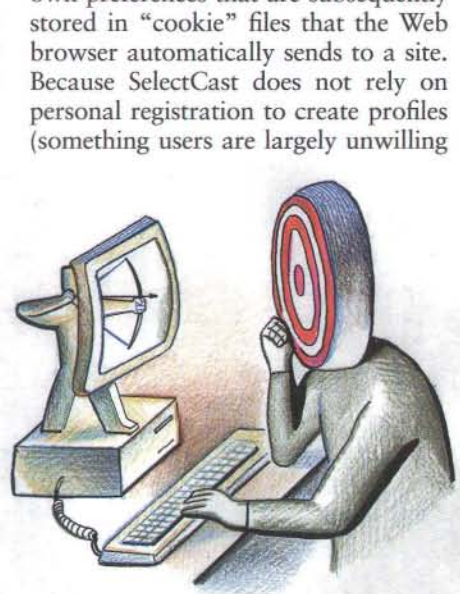
On-line Advertising Goes One-on-One

Amid sharply increasing Internet advertising revenues, a dizzying array of companies has formed to serve ads better, to track users more efficiently and to measure response rates to on-line ad campaigns more accurately. According to Cowles/Simba Information, a market research company, midyear revenue figures from ad sales for 1997 are up more than 250 percent from last year, and the annual figure for 1997 may top $400 million. Of course, that amount is still a far cry from the tremendous sums spent by advertisers in the print and broadcast media. To lure dollars away, Internet businesses have engaged in highly focused marketing—targeting and tailoring ads directly to individuals. Now improved software takes that targeting—or insidious intrusion, depending on your view—to a new level, one in which it may not be possible to avoid the watching eyes of advertisers.

SelectCast, a program offered to Web sites by Aptex Software in San Diego, is perhaps the most compelling. The program is a neural network (software that "learns" on its own) and relies on the same kind of pattern-matching technology used in detecting credit-card fraud. For SelectCast's purposes, you are what you do; "affinity profiles" are generated based on observed on-line behavior and adapt, via feedback loops, to user responses. In this scenario, clicking on an ad banner amounts to a kind of positive reinforcement by which the program learns about you. Likewise, "ad profiles" can be created, effectively indicating what kinds of users are apt to click on certain ads. The result is a fast, effective targeting system in which best-fit ads are selected in real time, on the fly.

Judging from the results achieved by the search engine Infoseek, which uses SelectCast under the name "Ultramatch," the software is very effective. The "click-through" response rates are twice as high on average as those for all advertising links across the rest of the Internet. For some ads, the figures are as much as five times higher, according to Peter Rip, a former vice president of the Infoseek Network. For Infoseek, this is no small development. Whereas search engines—the dominant ad forums online—have typically relied on the sale of key words to target ads (an automaker might pay to have its ads served to any users conducting a search on the word "car"), Ultramatch provides keyword-level performance for all the ads.

Moreover, SelectCast is unobtrusive, unlike the so-called collaborative filtering schemes in which users define their own preferences that are subsequently stored in "cookie" files that the Web browser automatically sends to a site. Because SelectCast does not rely on personal registration to create profiles (something users are largely unwilling



DAVID SUTER

to undertake), it can target a site's entire traffic. Even those surfers who disable the cookies in their browsers may be monitored without their knowledge via session ID, which logs when the user's machine connects to a site.

These abilities concern privacy advocates, who are hard-pressed to find a distinction between "unobtrusive" and "surreptitious." "All the defaults are set to collect," says Lori Fena of the Electronic Frontier Foundation. "What we object to," she continues, "is the collection of any user data without that user's informed consent."

For its part, Aptex emphasizes that it does not know or record personal information. It gets only an "irreversibly encoded" mathematical representation of affinities. Aptex concedes, however, that if a site were to use SelectCast with registration forms, they could correlate the two data sets, thereby obtaining more complete profiles of registered users.

The specter of that kind of data merging has already made the public leery. Consider the recent reversal of America Online's plans to sell information from its customer database. The company quickly backtracked in the face of widespread public indignation—despite the fact that magazines, charities and government agencies routinely sell the same type of information with impunity.

To account for this increased sensitivity, Rip, now at Knight Ridder Ventures, a venture-capital firm, points to a "subculture of distrust on the Internet fueled in part by the increased velocity of information." Indeed, the speed with which ads can be targeted to individuals is stunning, considering the sheer computational feat involved and the subtlety of the results. That advertisers may be able to exploit predilections and impulses of which we ourselves are perhaps unaware recalls another hobgoblin of public perception: subliminal advertising. Never mind that the effectiveness of subliminal ads has long been debunked in scientific circles; public suspicion still lingers.

How, then, will the public react to a demonstrably effective and far more complex system in which every keyword search, every page view, every click of the mouse is fed through an arcane black box aimed at influencing human behavior? Will neural nets be used to deliver content as well? Imagine a world in which we all see a different version of the newspaper, custom-tailored to our interests and political leanings. Wouldn't that encourage each of us—paradoxically—to become more like ourselves, to narrow our horizons rather than broaden them?

As with any radically new capability, companies in this game will ultimately have to reckon with the public's reluctance. To win its trust will require more openness and discourse—of which, so far, there have been very little. In turn, the public has a choice to make as well. Without a viable revenue stream, after all, the Internet cannot remain free. Subscription models have not proved practicable. Commerce still faces hurdles. But advertising—especially one-on-one advertising—is showing promise.

"What it boils down to," says Aptex's John Gaffney, "is that to do one-to-one we have to learn something about you." The public will be left to decide whether that is a price it is willing to pay.

—Patrick Joseph in San Francisco

Metal Clusters and Magic Numbers

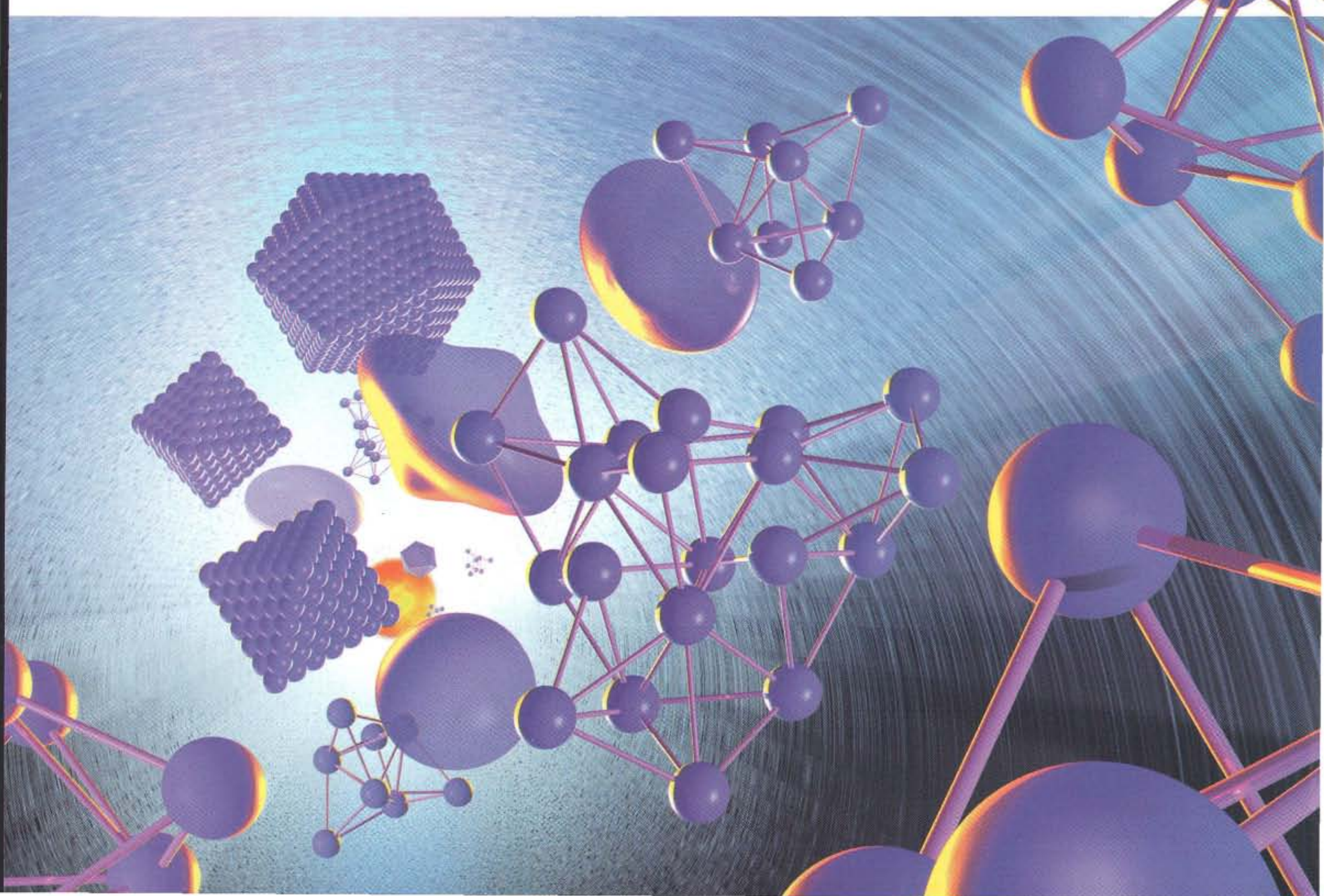
Investigations of tiny lumps of metal can help bridge the gap in physicists' understanding of the differences between isolated atoms and bulk solids

by Matthias Brack

Heat a small piece of metal until it starts to evaporate. Blow the vapor through a slim nozzle into a vacuum chamber. What happens? The spray of particles will condense into tiny clusters containing anywhere from a few to several thousand atoms of the metal. These metal clusters, much smaller than drops of water or grains of sand, constitute a fascinating new arrangement of matter.

Although most cluster experiments involve rather tiny objects, in principle, metal clusters can be arbitrarily large. These aggregates thus fall between isolated atoms or molecules and bulk solids or liquids. In this sense, they link the microcosm with the macrocosm. To a theoretical physicist, clusters present a host of intriguing questions: Why are some clusters more stable than others? How many atoms are needed before the properties of a cluster begin to resemble those of bulk matter? And how does the structure of a cluster change as more and more atoms join together?

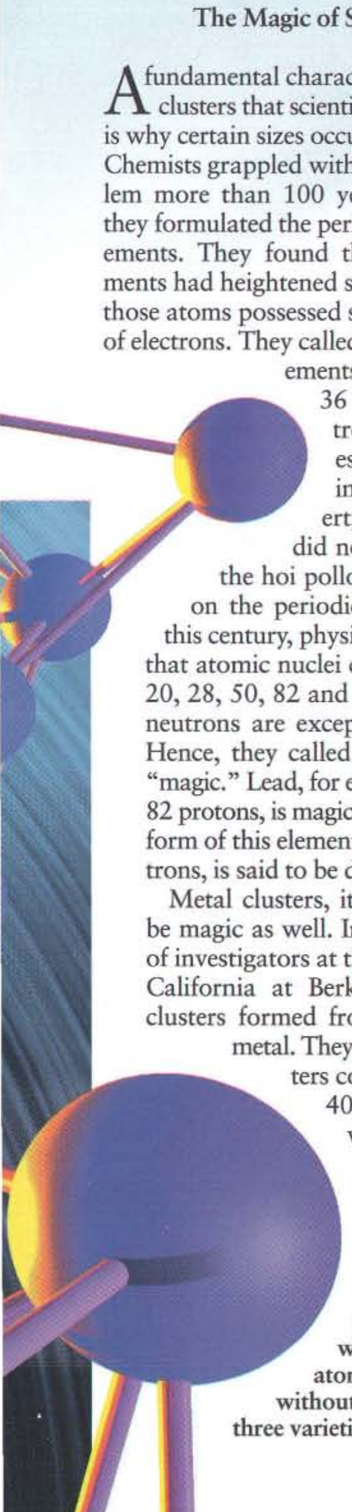
SLIM FILMS



But interest in metal clusters is not entirely restricted to theoretical physicists. For example, industrial chemists know from practice that metal clusters might make exceptionally good catalysts. Yet metal clusters may be difficult to harness more effectively until the principles underlying their formation are well understood—a goal that has come increasingly close to being realized over the past decade.

The Magic of Stability

A fundamental characteristic of metal clusters that scientists must explain is why certain sizes occur preferentially. Chemists grappled with a similar problem more than 100 years ago, when they formulated the periodic table of elements. They found that certain elements had heightened stability because those atoms possessed special numbers of electrons. They called the gaseous elements with 2, 10, 18, 36 and 54 electrons "noble gases" because, being chemically inert, these atoms did not interact with the hoi polloi sharing space on the periodic table. During this century, physicists discovered that atomic nuclei containing 2, 8, 20, 28, 50, 82 and 126 protons or neutrons are exceptionally stable. Hence, they called these numbers "magic." Lead, for example, with its 82 protons, is magically stable. (One form of this element, with 126 neutrons, is said to be doubly magic.)



Metal clusters, it turns out, can be magic as well. In 1984 a group of investigators at the University of California at Berkeley examined clusters formed from hot sodium metal. They found that clusters containing 8, 20, 40 or 58 atoms were much more abundant than other sizes. Clusters with these numbers of atoms predominated because, for some reason, they proved exceptionally stable.

Physicists now realize that unstable clusters produced at sufficiently high temperatures give off extra atoms and quickly turn into smaller, more stable clusters. Experimenters have found that the magic number sequence for stable clusters of hot sodium continues with 92, 138, 198, 264, 344, 442, 554 and higher numbers. Sodium clusters (and those of several other metals) with these numbers of atoms remain stable even when they are so hot they cannot solidify and remain only as droplets of liquid.

The tendency for clusters to form in exactly these sizes arises from the rules of quantum mechanics, which dictate that bound electrons can have only certain energies. In isolated atoms, electrons in excess of the numbers found in noble gas atoms are very loosely held and tend to stray far from the nuclei. These electrons are known as valence electrons and are responsible for various chemical properties of the different elements.

In a cluster of metal atoms (or a larger piece of metal), these valence electrons do not remain attached to the particular atoms in which they originally resided. Instead they flow rather freely between the atoms and are said to be delocalized. But they stay in or around the cluster because they are attracted to the now positive charges of the atoms they left behind. (With the valence electrons removed, the positive protons in the nuclei are no longer completely balanced by an equal number of negative electrons, and the formerly neutral atom becomes a positively charged ion.)

PARTICLE BEAM experiments send tiny amounts of metal coursing from a hot source through a long vacuum chamber. Depending on the experimental conditions imposed, the metal clusters created in this way may be small molecules with rigid bonds holding the atoms together, large groupings of atoms packed into regular polyhedral shapes or jellylike droplets without solid internal structure. Particularly stable examples of all three varieties arise in abundance, but not during a single experiment.

To understand why select numbers of atoms yield stability in a cluster, physicists would, ideally, want to determine the detailed configuration of all internal ions and valence electrons—something that is extremely difficult to ascertain. It turns out, however, that they can obtain answers for a metal cluster by modeling it as a smooth "jelly" of positive charge to which the valence electrons are attracted (a simplification known as the jellium model).

According to the rules of quantum mechanics, the energies of these electrons must be quantized—that is, the energy levels are of set amounts and never occur in intermediate values. And in a metal cluster, just as in an atom, the available energy levels for electrons are not equally spaced. They are grouped into bundles of close-lying levels, separated by larger spacings. For historical reasons, such bunches of energy levels in atoms are called electronic shells, although the electrons are not actually confined to shell-shaped regions. Quantum-mechanical rules limit the number of electrons that can reside in each shell, and if the electrons fill one or more shells in an atom completely, the atom does not react with others and thus proves exceptionally stable. So the existence of magic numbers for metal clusters makes some sense: they correspond to the number of valence electrons that completely fill one or more shells in a cluster and make it especially sturdy. (The same mechanism works for filled proton and neutron energy shells in atomic nuclei and explains their magic numbers.)

The metal clusters that show the greatest stability are nearly spherical. If the available electrons cannot fill the highest energy shell to capacity, however, the cluster can become flattened or elongated, and it begins to resemble a pancake or a football. Or it may take up a more complicated pear, lemon or diamondlike shape or a configuration with no particular symmetry. Such shapes reduce the total energy of the cluster, making it more stable—though not as stable as those clusters with completely

filled electronic shells. Physicists have long recognized that many stable atomic nuclei also have deformed shapes. So some of the theoretical tools for describing deformed clusters come from previous work in nuclear physics.

Supershells

The formalism of quantum mechanics fully accounts for the electronic shells of clusters and their corresponding magic numbers. But to many nonspecialists, this explanation is not very satisfying, because the rules of quantum mechanics often appear counterintuitive and are hard to visualize. Fortunately, it is possible to achieve some understanding of magic numbers using classical formulations that correspond to one's daily experience with macroscopic bodies.

This approach requires the periodic orbit theory, which scientists developed in the early 1970s to serve as a bridge between quantum mechanics and classical mechanics. Periodic orbit theory allows physicists to determine, with comparatively little effort, the energies for the major shells in a system containing electrons or other small particles.

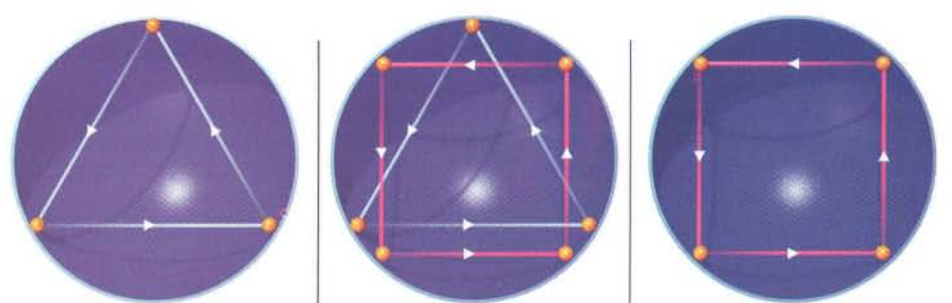
To visualize how periodic orbit theory applies to clusters, one can imagine that a large metal cluster is nothing but a hollow sphere containing valence electrons that move with constant velocity along straight lines. These electrons ricochet off the inner surface of the sphere with the angle of incidence equal to the angle of reflection, a general property that holds both for particles bouncing off a wall and for light waves being reflected by a mirror. This crude model works because the valence electrons are essentially free within the cluster but cannot leave it.

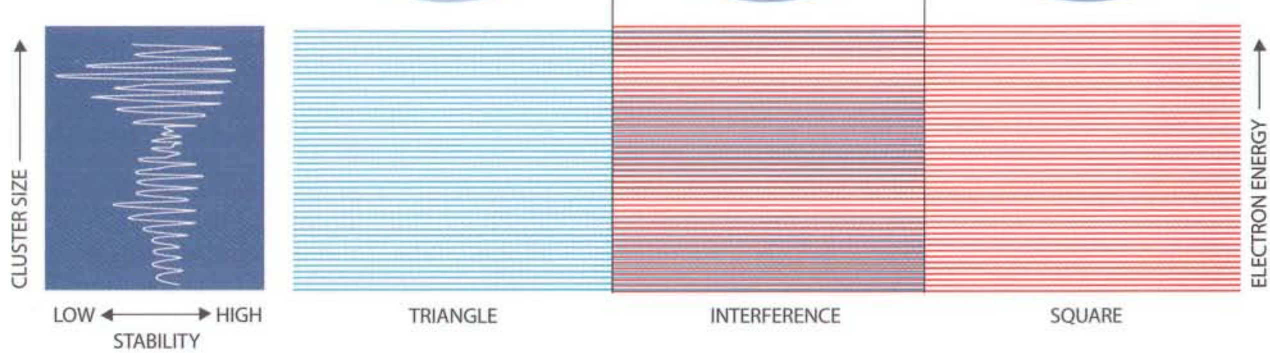
The periodic orbits in a spherical cavity are just the trajectories that the particles can take: they shoot back and forth along a diameter or follow around various polygons with three or more corners. Physicists can derive the approximate distribution of allowable energy levels by considering only the periodic orbits that have the shortest length and occur most frequently. The three shortest orbits are diameters, triangles and squares, but for subtle reasons having to do with the geometry, the diameters occur relatively infrequently.

Using only the triangles and squares, the calculation yields a pattern of energy shells that is, in a sense, periodic: when plotted as a function of energy, allowable levels appear at regular intervals. But the repetition does not occur at just one "frequency." Rather two different frequencies exist, corresponding to the two dominant orbits (triangles and squares). And much as two overlapping sound waves of similar frequency interfere with each other to produce lower-frequency "beats," the two sets of shells also interfere with each other to produce large-scale clustering of energy levels, termed supershells.

Supershells should, in principle, also occur in atomic nuclei. But they do not, because nuclei are never large enough to support them: it takes some 800 to 1,000 particles to give rise to the first supershell beat, whereas the largest nuclei created so far have fewer than 200 neutrons and 120 protons. But supershells can in fact be found in large metal clusters. In 1991 physicists at the Niels Bohr Institute in Copenhagen and at the Max Planck Institute for Solid State Research in Stuttgart observed supershells for hot sodium clusters. Shortly thereafter, researchers at the Aimé Cotton Laboratory in Orsay, France, found evidence for supershells in lithium clusters, and investigators at the University of Lyon-I detected supershells in gallium clusters.

The periodic orbit theory for the spherical cavity model predicts that the cube root of a magic number, which corresponds roughly to the radius of the corresponding cluster, should increase by the same amount from one shell to the next. And when researchers plot the cube roots of the magic numbers observed for various hot metal clusters against the shell number, they indeed obtain a straight line with a slope of 0.61. This result agrees with the periodic orbit theory for the spherical cavity (0.603) to within about 1 percent. The fuller

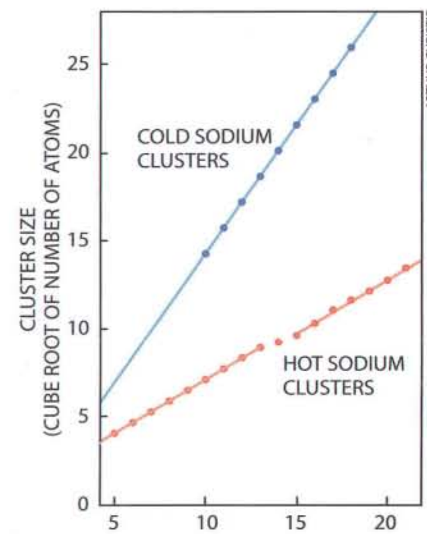




SIMPLIFIED MODEL of metal clusters treats them as hollow spheres with electrons bouncing inside (*right*). Using periodic orbit theory, physicists can calculate the approximate energy levels of the electrons (*horizontal bars*). The two most important kinds of periodic trajectories (*triangles* and *squares*) interfere to create clusterings of shells, called supershells. The supershell pattern is seen in experiments and in more sophisticated theoretical models (*below*).

SLIM FILMS

CLUSTER SIZE, expressed as the cube root of the number of atoms present, always grows with an increasing number of shells. But the rise (slope) depends on the temperature of the cluster beam. Cold sodium clusters consist of icosahedral shells of tightly packed atoms, a geometry that gives a characteristic slope of about 1.5. In contrast, the shape of hot sodium clusters is controlled by electronic shells, which give a slope of about 0.6. (The offset seen at shell number 14 is caused by supershell effects and is well explained by the periodic orbit theory.)



quantum-mechanical calculation using the jellium model, which is feasible only for clusters with up to a few thousand atoms (larger clusters would require an unreasonable amount of computing time), yields exactly the slope observed.

Perfect Polyhedra

The ancient Greek philosopher Plato had a vision that the building blocks of matter are regular polyhedra, the so-called Platonic solids. Curiously, in the case of cold metal clusters, he may not have been far wrong. When a large number of metal atoms (about 1,000 or more) aggregate slowly at relatively low temperatures, they form tiny solids in which the atoms pack themselves tightly, like oranges in a grocer's pile, to form regular geometric shapes.

Physicists can deduce the geometric configuration of these cold metal clusters by observing how their stability depends on their size. In 1991 researchers at the Max Planck Institute for Solid State Research allowed sodium atoms to coalesce at low temperatures and found that the most stable clusters formed in completely different sizes from those that occur at high temperatures. That is, an entirely new set of magic numbers operated. These investigators soon concluded that the newly observed magic numbers corresponded to collections of atoms packed into perfect icosahedra, 20-sided solids with triangular faces.

In such experiments, a specific sequence of magic numbers arises as larger and larger icosahedra form through the addition of layers of sodium that are only one atom thick. These "atomic shells" resemble, in a crude sense, the layered skin of an onion. The simple polyhedral shapes formed in this way are more stable than irregular arrangements because the energy required to hold the atoms in place is reduced when the number of edges is minimized. Nature, it seems, likes the economy of perfect polyhedra.

The magic numbers for cold metal clusters, when plotted in terms of their cube roots, increase with the number of atomic shells—but not at the same rate that the magic numbers of hot metal clusters increase with the number of electronic energy shells. And the sharpness of the rise, or slope, changes for various kinds of cold clusters. Different slopes, it seems, signal the presence of different polyhedral shapes. For example, cold clusters of sodium or calcium, which give a slope of about 1.5, most likely form icosahedra. And clusters containing equal numbers of atoms of sodium and iodine, or sodium and chlorine, produce a slope of exactly 1.0, indicating that they form cubes. Why one shape occurs rather than another remains something of a mystery.

Cold clusters of aluminum or indium pose an especially interesting puzzle. On plotting the cube roots of their magic numbers as a function of shell number, investigators find a slope of 0.220, which is less than the value for stable electronic shells (0.6) but different from the slopes for atoms packed into tetrahedra (0.550), octahedra (0.874), icosahedra (1.493) or cubes (1.0). In fact, it is not possible to find a regular polyhedron of any kind that, when coated with additional layers of atoms, gives the set of magic numbers observed for these clusters.

Members of the Stuttgart group have proposed one possible solution—that such aluminum or indium clusters grow as octahedra but that in going from one magic number to the next, only enough atoms are added to cover one triangular facet at a time. This behavior would lead to the shallow slope that is seen. Their explanation seems plausible, but it immediately raises a new, as yet unanswered question: Why are complete octahedra not much more stable than those with only one or two triangular facets added?

Interestingly, the magic numbers arising from atomic packing do not uniquely determine the shape of the polyhedra involved. For example, the magic numbers associated with icosahedra coincide with magic numbers that would be found for cubo-octahedra (cubes with their corners cut off). Careful study of cold calcium clusters has suggested to scientists that it is the icosahedra that form. Yet we cannot be sure—nobody has seen the icosahedra directly. In principle, the largest clusters could be viewed with an electron microscope if they were at rest. The problem is that free clusters are formed in beams of swiftly moving atoms, and they cannot be stopped for a picture without altering their shapes.

Competing Masters

In metal clusters composed of a large number of atoms, the two kinds of shells (electronic energy shells and atomic shells forming perfect polyhedra) compete for control over form and stability of the cluster. Size and temperature are critical in determining which type of shell prevails. But to measure the temperature of isolated clusters traveling in a beam is quite difficult; one might even ask whether a temperature can be defined at all. Strictly speaking, temperature is meaningful only for systems of many particles in thermodynamic equilibrium. But this condition is not realized in most cluster experiments. Rather each cluster formed in a beam follows its own path, unaffected by its neighbors. Such isolated clusters do not attain thermodynamic equilibrium. So, short of sticking a thermometer against a tiny cluster under study—an experimental impossibility—there is no easy way to determine its temperature.

Still, the trends are clear. By heating the nozzle of the source under carefully controlled conditions, the shells of neatly packed icosahedra in cold sodium clusters seem to disappear. This transition presumably corresponds to the

melting of solid clusters. The melting temperature in this case depends on the size of the cluster.

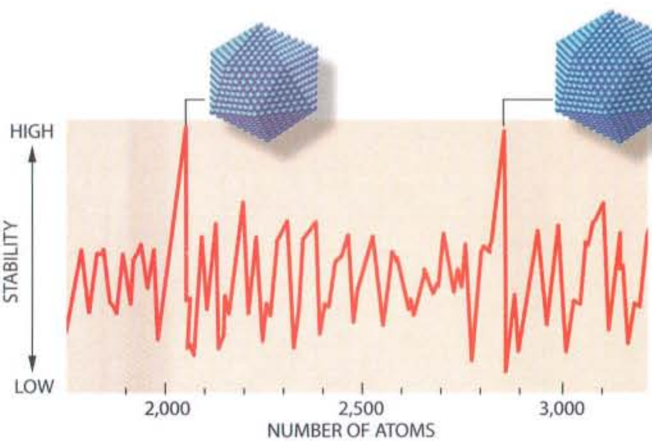
Researchers have found a similar transition in clusters made of aluminum. When the temperature of the source exceeds 500 kelvins, which is still far below the melting temperature of bulk aluminum, plots of the cube root of magically stable cluster sizes versus shell number cease to exhibit the slope of 0.220 (the number that suggests the packing of atoms on the facets of perfect octahedra). Instead they show a slope of about 0.6, which is typical of electronic shells. It seems reasonable to surmise that these clusters have become molten, even though the temperature of the nozzle is well below the melting point of the bulk metal. But that conclusion may be overly simplistic: as with temperature, the notion of a phase transition between solid and liquid itself becomes problematic for objects of this size. Perhaps the clusters are experiencing a local melting of their surfaces that is sufficient to destroy the structure controlled by the packing of ions, allowing the stability conferred by completed electronic shells to reign.

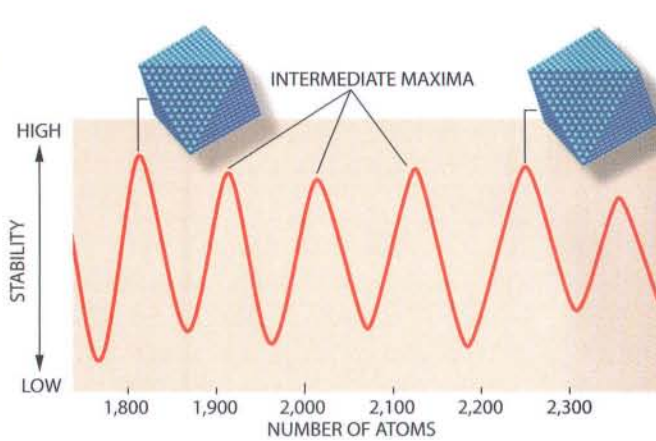
Physicists at the University of Freiburg have recently observed a somewhat different but related transition. To

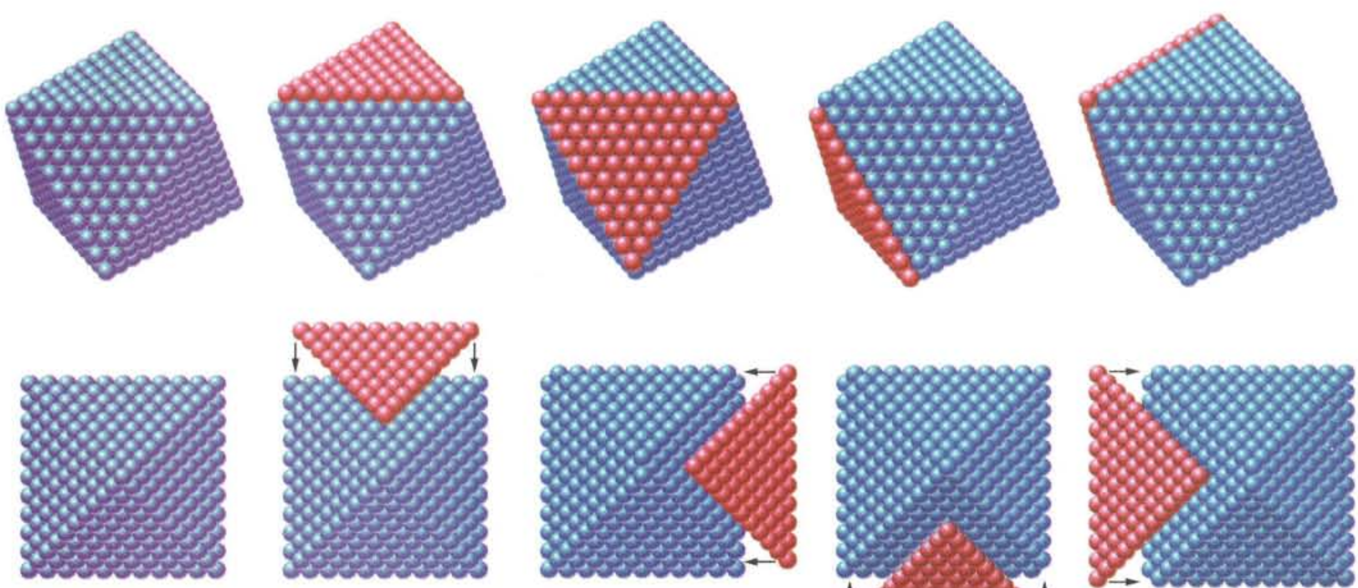
Packing for the Cold

Scientists can explain the exceptional stability of cold metal clusters with geometry. For example, cold clusters of sodium prove especially stable when the atoms pack neatly into an icosahedron, a 20-sided solid. Hence, charts of stability as a function of cluster size show distinct peaks when the number of atoms available is such that they form perfect icosahedra (*left*).

Cold clusters of aluminum atoms, which pack into tiny octahedra, prove somewhat more difficult to explain. Stability is high when the atoms pack into perfect octahedra (*right*), but maxima also occur at intermediate sizes. The reason may be that enhanced stability also arises when atoms cover individual faces of an octahedron (*red layers, below*). Because adding a fourth additional face completes an octahedron of the next largest size, only three intermediate stability maxima are expected. *—M.B.*

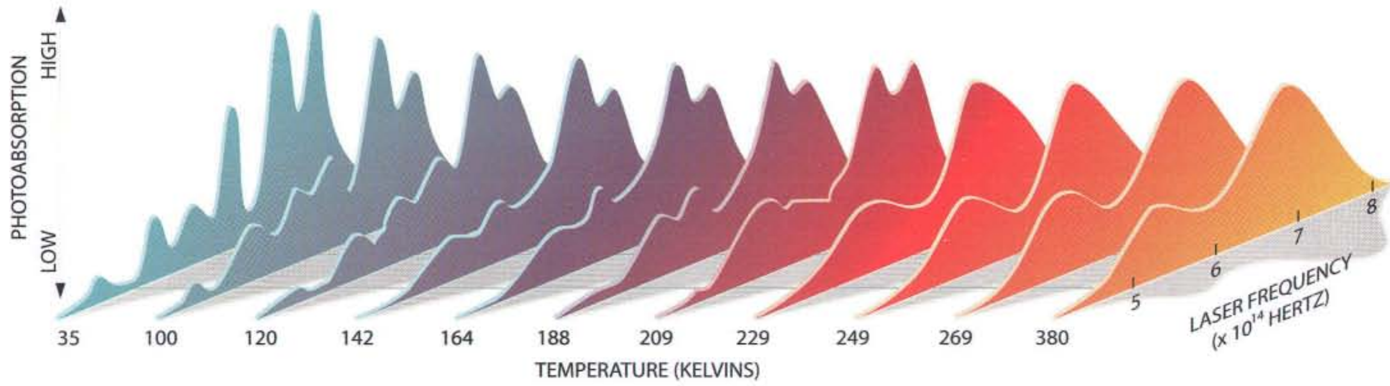






891-ATOM OCTAHEDRON ONE FACE ADDED TWO FACES ADDED THREE FACES ADDED 1,156-ATOM OCTAHEDRON

SLIM FILMS; SOURCE: T. P. MARTIN *Max Planck Institute for Solid State Research*



LASER PHOTOABSORPTION SPECTRA reveal that clusters are transformed from rigid molecules to structureless masses as temperature rises. The probability of photon absorption varies markedly with laser frequency, a characteristic of molecules, for clusters of sodium held at low temperatures (*blue shades*). But at high temperatures (*orange shades*), the spectra smooth to show just two broad humps, consistent with the so-called jellium model that physicists use for clusters lacking internal structure.

ARTHUR CHRISTIE; SOURCE: MARTIN SCHMIDT AND HELLMUT HABERLAND *University of Freiburg*

control the temperature of small sodium clusters in a better way, they used a clever trick: they embedded the clusters in helium gas, for which they could adjust the temperature quite accurately. In this mixture of helium atoms and sodium clusters, many collisions take place. But because helium is a noble gas (that is, it remains chemically inactive), it does not change the structure of the clusters—at least at moderate temperatures. So the helium provides an environment in which a thermodynamic equilibrium can establish itself.

What the scientists examined in this case were not magic numbers but the way in which sodium clusters of one fixed size absorb the light of a laser beam. The probability for light absorption as a function of laser frequency (the absorption spectrum) can reveal much about the physical condition of the particles illuminated. In particular, the spectra for cold, rigid molecules and hot, liquid droplets differ. For temperatures below 100 kelvins, the experimenters observed a spectrum with many sharp peaks, which is typical of a rigid molecule, whereas for temperatures above 380 kelvins, they found a spectrum with just two broad humps, positioned as one would predict theoretically for an unstructured jelly.

For the smallest clusters, where the internal structure is always important, rigorous quantum-mechanical calculations that take into account all electrons in each atom are possible. They reveal the detailed molecular structure of the clusters and can give quite precise descriptions of their stability. For larger aggregates with some hundred atoms or more, such calculations take up too much computing time to carry out, and physicists have to invoke the jellium model. For clusters with many thousands of atoms, researchers must abandon quantum mechanics and invoke the simplified periodic orbit theory or rely on indirect information from the magic numbers found experimentally.

Scientists have come a long way since 1984 in understanding and extending magic number sequences in metal clusters. Some experiments have produced icosahedral sodium clusters made up of as many as 21,000 atoms. Yet it is clear that sodium in bulk does not contain such icosahedra. In fact, no bulk material can be built up by packing icosahedra together: just as pentagonal tiles cannot be made to cover a plane, icosahedra lack the symmetry needed to form extended crystals in three dimensions by filling out the space completely. So even the most massive sodium clusters produced so far have their atoms organized quite differently from the way they occur in bulk sodium.

Part of the initial motivation for studying clusters was to determine how many atoms are required for a tiny lump of material to attain the properties of the bulk solid. Physicists have learned a great deal about metal clusters and the magic number sizes that bring stability to them. But we still do not know the answer to this fundamental question about when and how the transition to the bulk solid occurs. All we can say for now is that the clusters of metal atoms we have studied constitute a weirdly unique arrangement of matter, one that surely offers more surprises to come. SA

The Author

MATTHIAS BRACK received his education in physics at the Niels Bohr Institute in Copenhagen and at the University of Basel, where he received a Ph.D. in 1972. He has done research on nuclear physics at the Niels Bohr Institute, at the State University of New York at Stony Brook and at the Laue Langevin Institute in Grenoble. Since 1978 he has been a professor of theoretical physics at the University of Regensburg in Germany.

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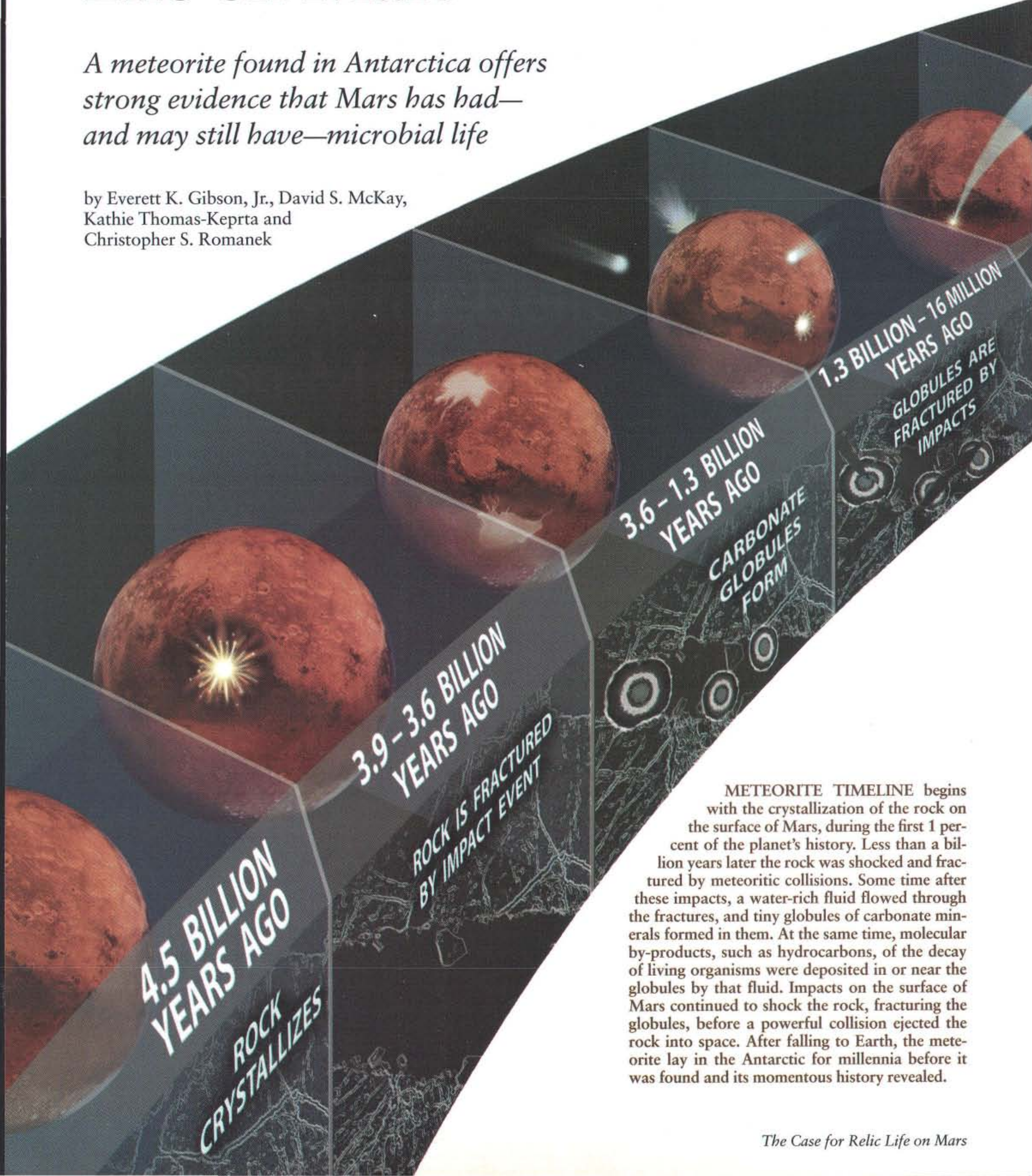
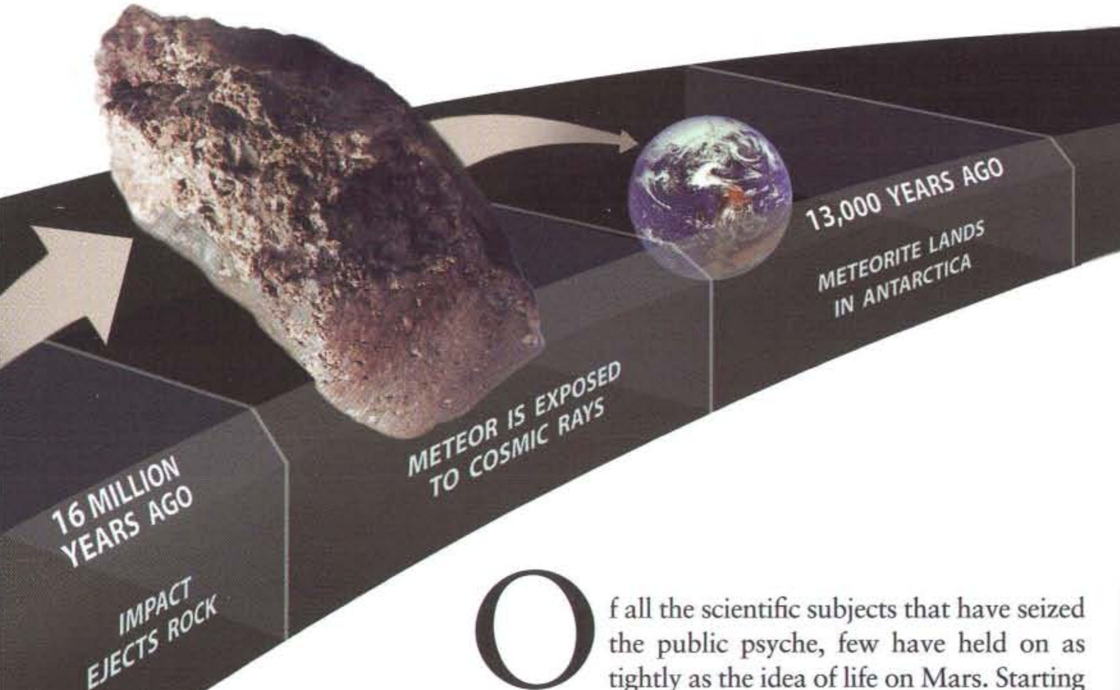
The Case for Relic Life on Mars

A meteorite found in Antarctica offers strong evidence that Mars has had—and may still have—microbial life

by Everett K. Gibson, Jr., David S. McKay, Kathie Thomas-Keprta and Christopher S. Romanek



METEORITE TIMELINE begins with the crystallization of the rock on the surface of Mars, during the first 1 percent of the planet's history. Less than a billion years later the rock was shocked and fractured by meteoritic collisions. Some time after these impacts, a water-rich fluid flowed through the fractures, and tiny globules of carbonate minerals formed in them. At the same time, molecular by-products, such as hydrocarbons, of the decay of living organisms were deposited in or near the globules by that fluid. Impacts on the surface of Mars continued to shock the rock, fracturing the globules, before a powerful collision ejected the rock into space. After falling to Earth, the meteorite lay in the Antarctic for millennia before it was found and its momentous history revealed.



Of all the scientific subjects that have seized the public psyche, few have held on as tightly as the idea of life on Mars. Starting not long after the invention of the telescope and continuing for a good part of the past three centuries, the subject has inspired innumerable studies, ranging from the scientific to the speculative. But common to them all was recognition of the fact that in our solar system, if a planet other than Earth harbors life, it is almost certainly Mars.

Interest in Martian life has tended to coincide with new discoveries about the mysterious red world. Historically, these discoveries have often occurred after one of the periodic close approaches between the two planets. Every 15 years, Mars comes within about 56 million kilometers of Earth (the next approach will occur in the summer of 2003). Typically, life on Mars was assumed to be as intelligent and sophisticated as that of *Homo sapiens*, if not more so. (Even less explicably, Martian beings have been popularly portrayed as green and diminutive.)

It was after one of the close approaches in the late 19th century that Italian astronomer Giovanni V. Schiaparelli announced that he had seen great lines stretching across the planet's surface, which he called *canali*. At the turn of the century, U.S. astronomer Percival Lowell insisted that the features were canals constructed by an advanced civilization. In the 1960s and 1970s, however, any lingering theories about the lines and elaborate civilizations were put to rest after the U.S. and the Soviet Union sent the first space probes to the planet. The orbiters showed that there were in fact no canals, although there were long, huge canyons. Within a decade, landers found no evidence of life, let alone intelligent life and civilization.

Although the debate about intelligent life was essentially over, the discussions about microbial life on the planet—particularly life that may have existed on the warmer, wetter Mars of billions of years ago—were just beginning. In August 1996 this subject was thrust into the spotlight when we and a number of our colleagues at the National Aeronautics and Space Administration Johnson Space Center and at Stanford University announced that unusual characteristics in a meteorite known to have come from Mars could most reasonably be interpreted as the vestiges of ancient Martian bacterial life. The 1.9-kilogram, potato-sized meteorite, designated ALH84001, had been found in Antarctica in 1984.

Our theory was by no means universally embraced. Some researchers insisted that there were nonbiological explanations for the meteorite's peculiarities and that these rationales were more plausible than our biological explanation. We remain convinced that the facts and analyses that we will outline in this article point to the existence of a

1984

METEORITE COLLECTED IN ANTARCTICA

1993

SAMPLE ALH84001 IDENTIFIED AS METEORITE FROM MARS

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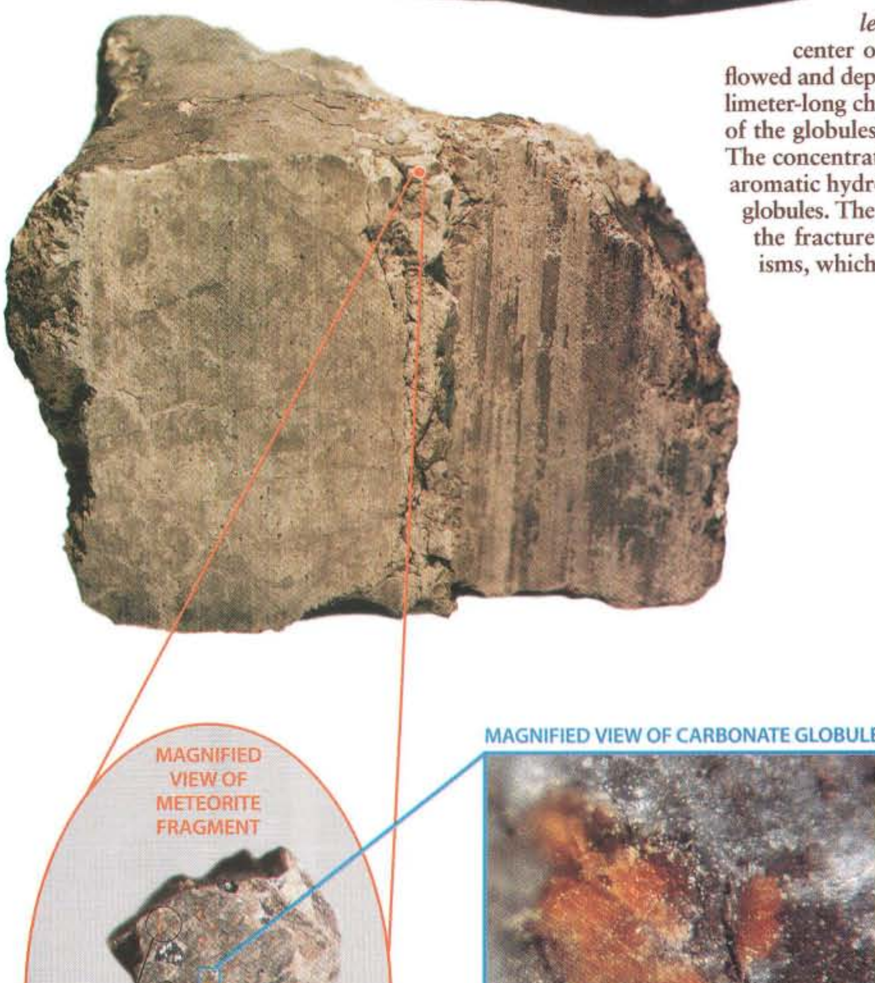
PHOTOGRAPHS BY NASA JOHNSON SPACE CENTER; DIGITAL COMPOSITION BY JENNIFER C. CHRISTIANSEN

NASA JOHNSON SPACE CENTER



NASA JOHNSON SPACE CENTER

JOHN W. VALLEY *University of Wisconsin–Madison*

MARTIAN ROCK, also known as ALH-84001, is shown here (*top left*) at actual size. The meteorite consists mostly of orthopyroxene, a silicate mineral. The rock was cut, exposing a cross section (*middle left*). The vertical crack slightly to the right of the center of the cut face is a fracture through which fluid flowed and deposited globules of carbonate minerals. A two-millimeter-long chip of the meteorite (*bottom left*) contains several of the globules, which are approximately 200 microns across. The concentration of organic compounds known as polycyclic aromatic hydrocarbons is highest in and around the carbonate globules. The finding suggests that the fluid that flowed through the fracture contained the decay products of living organisms, which were trapped by the forming globules.

primitive form of life. Moreover, such life-forms may still exist on Mars if, as some researchers have theorized, pore spaces and cracks in rocks below the surface of the planet contain liquid water.

Why should researchers even care about the possible existence of such a simple form of life billions of years ago on the red planet? Certainly, the prevalence of life in the universe is among the most profound scientific questions. Yet almost no hard data exist that can be used to theorize on that issue. Confirmation that primitive life once flourished on Mars would be extremely useful to those studying the range of conditions under which a planet can generate the complex chemistry from which life evolves. Then, too, the information could help us understand the origin of life on Earth. Ultimately, these kinds of insights could elucidate various hypotheses—which are currently little more than guesses—about how common life is in the universe.

Inhospitable Planet

Conditions on Mars today are not hospitable to life as we know it. The planet's atmosphere consists of 95 percent carbon dioxide, 2.7 percent ni-

trogen, 1.6 percent argon and only trace amounts of oxygen and water vapor. Surface pressure is less than 1 percent of Earth's, and daily temperatures rarely exceed zero degrees Celsius, even in the planet's warmest regions in the summer. Most important, one of life's most fundamental necessities, liquid water, seems not to exist on the planet's surface.

Given these realities, it is perhaps not surprising that the two Viking space probes that settled on the planet's surface, in July and September of 1976, failed to find any evidence of life. The results cast doubt on—but did not completely rule out—the possibility that there is life on Mars. The landers, which were equipped to detect organic compounds at a sensitivity level of one part per billion, found none, either at the surface or in the soil several centimeters down. Similarly, three other experiments found no evidence of microbial organisms. Ultimately, researchers concluded that the possibility of life on Mars was quite low and that a more definite statement on the issue would have to await the analysis of more samples by future landers—and, it was hoped, the return of some samples from the red planet for detailed study on Earth.

Although the landers found no evidence of life on present-day Mars, photographs of the planet taken from orbit by the Viking craft, as well as earlier images made by the Mariner 9 probe, strongly suggest that great volumes of water had sculpted the planet's surface a few billion years ago and perhaps as recently as several hundred million years ago [see "Global Climatic Change on Mars," by Jeffrey S. Kargel and Robert G. Strom; SCIENTIFIC AMERICAN, November 1996].

In addition, various meteorites found on Earth and known to be of Martian origin—including ALH84001 itself—offer tangible proof of Mars's watery past because they show unambiguous signs of having been altered by water. Specifically, some of these meteorites have been found to contain carbonates, sulfates, hydrates and clays, which can be formed, so far as planetary scientists know, only when water comes into contact with other minerals in the rock.

Of course, the entire argument hinges on ALH84001's having come from the red planet. Of this, at least, we can be certain. It is one of several meteorites found since the mid-1970s in meteorite-rich regions in Antarctica [*see box on next two pages*]. In the early 1980s Donald D. Bogard and Pratt Johnson of the NASA Johnson Space Center began studying a group of meteorites found to contain minute bubbles of gas trapped within glass inside the rock. The glass is believed to have formed during impacts with meteoroids or comets while the rock was on the surface of Mars. Some of these glass-producing impacts apparently imparted enough energy to eject fragments out into space; from there, some of these rocks were captured by Earth's gravitational field. This impact scenario is the only one that planetary scientists believe can account for the existence on our world of bits of Mars.

Bogard and Johnson found that the tiny samples of gas trapped in the glass of some of the meteorites had the exact chemical and isotopic compositions as gases in the atmosphere of Mars, which had been measured by the Viking landers in 1976. The one-to-one correlation between the two gas samples—over a range of nine orders of magnitude—strongly suggests that these meteorites are from Mars. In all, five meteorites have been shown to contain samples of trapped Martian atmosphere. ALH-84001 was not among the five so analyzed; however, its distribution of oxygen isotopes, minerology and other characteristics place it in the same group with the other five Martian rocks.

The distribution of oxygen isotopes within a group of meteorites has been the most convincing piece of evidence establishing that the rocks—including ALH84001—come from Mars. In the early 1970s Robert N. Clayton and his co-workers at the University of Chicago showed that the isotopes oxygen 16, oxygen 17 and oxygen 18 in the silicate materials within various types of meteorites have unique relative abundances. The finding was significant because it demonstrates that the bodies of our solar system formed from distinct regions of the solar nebula and thus have unique oxygen isotopic compositions. Using this isotopic "fingerprint," Clayton helped to show that a group of 12 meteorites, including ALH84001, are indeed closely related. The combination of trapped Martian atmospheric gases and the specific distribution of oxygen isotopes has led researchers to conclude that the meteorites must have come from Mars.

Invader from Mars

Other analyses, mainly of radioisotopes, have enabled researchers to outline ALH84001's history from its origins on the red planet to the present day. The three key time periods of interest are the age of the rock (the length of time since it crystallized on Mars), how long the meteorite traveled in space and how long it has been on Earth. Analysis of three different sets of radioactive isotopes in the meteorite have established each of these time periods.

The length of time since the rock solidified from molten materials—the so-called crystallization age of the material—has been determined through the use of three different dating techniques. One uses isotopes of rubidium and strontium, another, neodymium and samarium, and the third, argon. All three methods indicated that the rock is 4.5 billion years old. By geologic standards the rock is extremely old; the 4.5-billion-year figure means that it crystallized within the first 1 percent of Mars's history. In comparison, the other 11 Martian meteorites that have been analyzed are all between 1.3 billion years old and 165 million years old. It is remarkable that a rock so old, and so little altered on Mars or during its residence in the Antarctic ice, became available for scientists to study.

The duration of the meteorite's space odyssey was determined through the

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MARTIAN WATER droplet was extracted by heating a chip of a meteorite from Mars. Researcher Haraldur R. Karlsson and his colleagues at the National Aeronautics and Space Administration Johnson Space Center performed the extraction in 1991. Liquid water, which existed on the surface of Mars in the past, is a requirement for life.

analysis of still other isotopes, namely helium 3, neon 21 and argon 38. While a meteorite is in space, it is bombarded by cosmic rays and other high-energy particles. The particles interact with the nuclei of certain atoms in the meteorite, producing the three isotopes listed above. By studying the abundances and production rates of these cosmogenically produced isotopes, scientists can determine how long the meteorite was exposed to the high-energy flux and, therefore, how long the specimen was in space. Using this approach, researchers concluded that after being torn free from the planet, ALH84001 spent 16 million years in space before falling in the Antarctic.

To determine how long the meteorite lay in the Antarctic ice, A. J. Timothy Jull of the University of Arizona used carbon 14 dating. When silicates are exposed to cosmic rays in space, carbon 14 is produced. In time, the rates of production and decay of carbon 14 balance, and the meteorite becomes saturated with the isotope. The balance is upset when the meteorite falls from space and production of carbon 14 ceases. The decay goes on, however, reducing the amount in the rock by one half every 5,700 years. By determining the difference between the saturation level and the amount measured in the silicates, researchers can determine how long the meteorite has been on Earth. Jull's finding was that ALH84001 fell from space 13,000 years ago.

From the very moment it was discovered, the meteorite now known as ALH84001 proved unusual and intriguing. In 1984 U.S. geologist Roberta Score found the meteorite in the Far Western Icefield of the Allan Hills Region. Score recognized that the rock was unique because of its pale greenish-gray color. The sample turned out to consist of 98 percent coarse-grained orthopyroxene [$(Mg,Fe)SiO_3$], a silicate mineral. There are also relatively minor amounts of feldspathic glass, which is also known as maskelynite ($NaAlSi_3O_8$), olivine [$(Mg,Fe)_2SiO_4$], chromite ($FeCr_2O_4$) and pyrite (FeS_2) as well as carbonate phases and phyllosilicates.

Carbonates Are Key

The most interesting aspect of ALH84001 are the carbonates, which exist as tiny discoids, like flattened spheres, 20 to 250 microns in diameter. They cover the walls of cracks in the meteorite and are oriented in such a way that they are flattened against the inside walls of the fractures [*see illustration on page 38*]. The globules were apparently deposited from a fluid saturated with carbon dioxide that percolated through the fracture after the silicates were formed. None of the other 11 meteorites known to have come from Mars have such globules.

It was within the carbonate globules that our research team found the assortment of unique features that led us to hypothesize that microbial organisms came into contact with the rock in the distant past. Basically, the case for ancient microbial life on Mars is built almost entirely around the globules.

Individually, none of the features we found are strongly indicative of life. Collectively, however—and especially within the confines of the tiny discoids—the globules can be plausibly explained as the ancient vestiges of microbial life. The features fall into several categories of evidence. One category centers on the presence of tiny iron oxides and iron sulfide grains, which resemble those formed by terrestrial bacteria. The second group revolves around the presence of organic carbon molecules in and on the globules. Finally, unusual structures found within the globules bear a striking resemblance to bacteria fossils found on Earth. Another relevant piece of evidence suggests the globules formed from a water-rich fluid below 100 degrees C.

NASA Johnson Space Center researchers, along with Monica Grady of the British Museum of Natural History and workers at the Open University in the U.K., performed the first isotopic analysis of carbon and oxygen in the carbonate globules. The carbon analysis indicates that the globules have more carbon 13 than any carbonates found on Earth but just the right amount to have come from Mars.

Most carbon on Earth is made up of 98.9 percent carbon 12 and 1.1 percent carbon 13. Various reactions, however, can alter this ratio. For example, in general a sample of carbon that has been a part of an organic chemical system—


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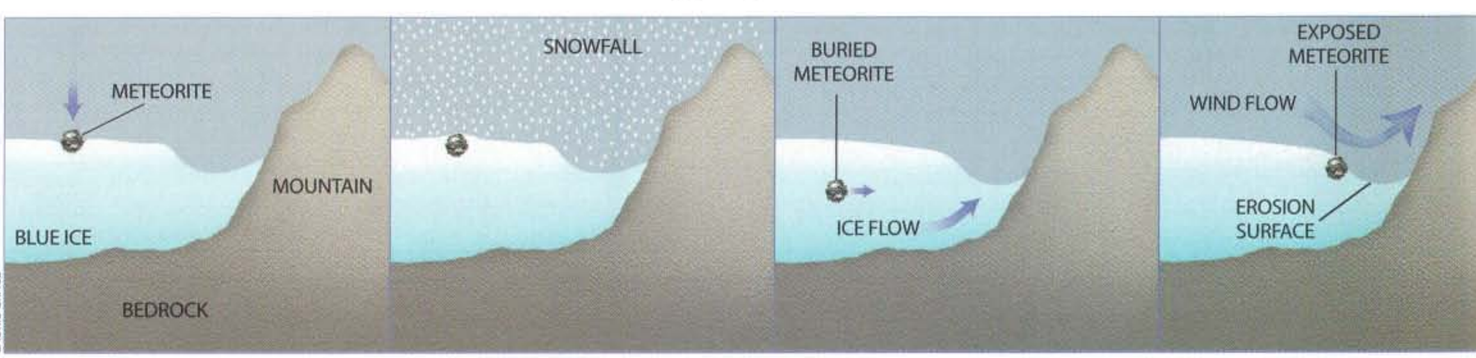
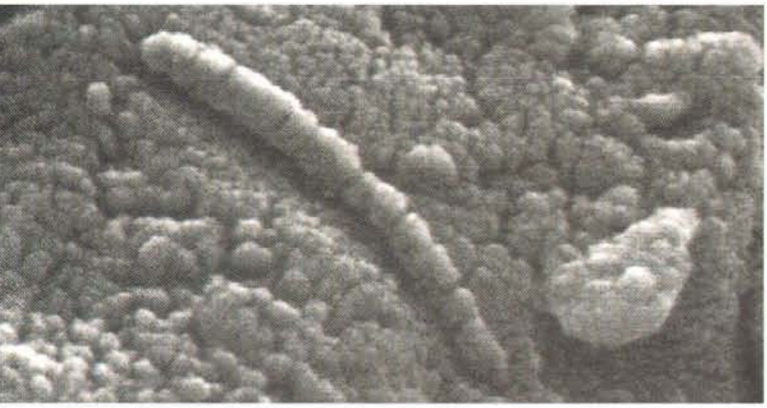
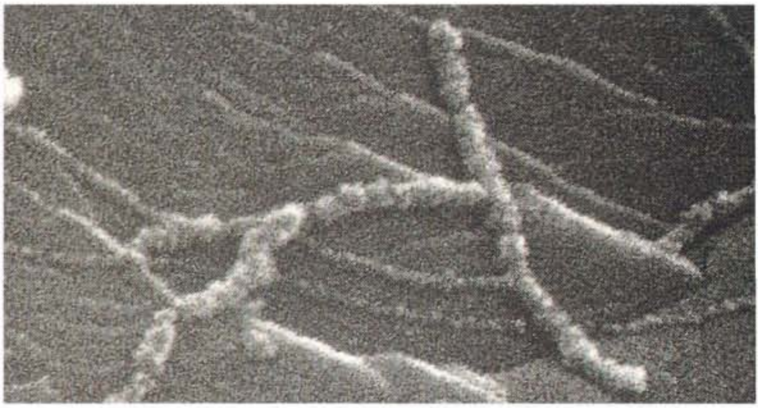
The Budget Space Probe



LAURIE GRACE

A combination of geologic and meteorological phenomena gather meteorites at the bases of Antarctica's mountains. After landing, the meteorites become buried in compressed snow, which eventually becomes ice. Sheets of ice move toward the edges of the continent, carrying the meteorites with them. If a mountain blocks horizontal movement of the meteorites, they will in time become exposed near the mountain. The reason is that the winds slowly but continuously "ablate" the ice above the meteorites, turning it into a gas. Ablation exposes areas of ice that had been buried deep under the surface, so meteorites are found on ice that is generally more than 10,000 years old and is bluish in color.





SEGMENTED OBJECT (*above, left*) is 380 nanometers in length and was found in a carbonate globule in meteorite ALH84001. The minute structure resembles fossilized bacteria, or microfossils, found on Earth. For example, the vertically oriented object to the right in the right-hand photograph is believed to be a microfossil. The object, which is also 380 nanometers long, was found 400 meters below Earth's surface (in Washington State) in a type of geologic formation known as Columbia River Basalt.

say, in plant matter—is somewhat more enriched in carbon 12, whereas carbon in limestone is relatively enriched in carbon 13. The carbon in the globules of ALH84001 is more enriched in carbon 13 than any natural materials on Earth. Moreover, the enrichment is different from that of the other 11 Martian meteorites. This fact suggests that the carbon in the globules—unlike the trace amounts of carbon seen in the other Martian meteorites—may have been derived from Mars's atmosphere.

Analysis of the distribution of oxygen isotopes in the carbonates can provide information about the temperature at which those minerals formed. The subject bears directly on the question of whether the carbonates were formed at temperatures that could support microbial life, because terrestrial organisms do not survive at temperatures above about 115 degrees C. The NASA-U.K. team analyzed the oxygen isotopes in the carbonate globules. Those findings strongly suggest that the globules formed at temperatures no higher than 100 degrees C. Earlier this year John W. Valley of the University of Wisconsin–Madison used an ion microprobe technique to confirm our finding.

It should be noted that another research group, led by Ralph P. Harvey of Case Western Reserve University, has analyzed the chemical composition of the minerals in the carbonates with an electron microprobe and concluded that the carbonates formed at 700 degrees C. In our view, Harvey's findings are at odds with a growing body of evidence that the globules formed at relatively low temperatures.

We are extremely interested in the age of the carbonates, because it would allow us to estimate when microbial life left its mark on the rock that became ALH84001. Yet all we can say for sure is that the carbonates crystallized in the fractures in the meteorite some time after the rock itself crystallized. Various research groups have come up with ages ranging from 1.3 to 3.6 billion years; the data gathered so far, however, are insufficient to date the carbonate globules conclusively.

Biomineral Clues

The first category of evidence involves certain minerals found inside the carbonate globules; the type and arrangement of the minerals are similar, if not identical, to certain bio-

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In 1969 a team of Japanese glaciologists working near the Yamato Mountains in Antarctica discovered eight meteorites in an ice field known to be more than 10,000 years old. The discovery was remarkable because the meteorites were of four different types, indicating that they could not have all fallen at the same time, as fragments of the same meteorite.

It did not take glaciologists long to figure out how ice flows consolidate the rocks. Meteorites landing on the Antarctic ice become buried in compressed snow, called firn, which in time becomes ice. This ice eventually becomes "old" ice, which is bluish in color.

Propelled by gravity, masses of ice move at a rate of about two to three meters a year from the relatively lofty interior of the Antarctic continent to the edges (*left*). If an obstacle such as a mountain range impedes the flow of ice, the ice mass pushes upward against the barrier. The ice—and the meteorites it contains—can make no more horizontal progress. In the meantime, as the winds blow over it, the surface layer of ice is slowly removed by a process known as ablation. Ablation, in which the solid ice converts directly to a gas, removes typically two to three centimeters of ice per year. As ice is removed, the meteorites within are exposed on the surface of the ice sheet. The end result is that meteorites are continuously accumulating and being exhumed at the base of Antarctica's mountains. Because ablation exposes areas of ice that had been buried deep under the firn, the meteorites are always found on regions of old, bluish ice. Nowhere else in the world does this marvelous concentration mechanism occur. Only the Antarctic has the necessary combination of moving glaciers and mountainous barriers.

Over the past 28 years, scientific teams have recovered more than 17,000 meteorites. The vast majority of samples came from the asteroid belt, but the Antarctic harvest has also yielded 14 samples from the moon and six from Mars.

Delivered as they are free of charge, meteorites have been called the poor man's space probe. Before the discovery of the Antarctic meteorite cache, the world's meteorite collections had only between 2,000 and 2,500 different specimens.

—E.K.G., D.S.M., K.T.-K. and C.S.R.

minerals found on Earth. Inside, the globules are rich in magnesite ($MgCO_3$) and siderite ($FeCO_3$) and have small amounts of calcium and manganese carbonates. Fine-grained particles of magnetite (Fe_3O_4) and sulfides ranging in size from 10 to 100 nanometers on a side are present within the carbonate host. The magnetite crystals are cuboid, teardrop or irregular in shape. Individual crystals have well-preserved structures with little evidence of defects or trace impurities.

An analysis of the samples conducted with high-resolution transmission electron microscopy coupled with energy-dispersive spectroscopy indicates that the size, purity, morphology and crystal structures of all these magnetites are typical of magnetites produced by bacteria on Earth.

Terrestrial magnetite particles associated with fossilized bacteria are known as magnetofossils. These particles are found in a variety of sediments and soils and are classified, according to size, as superparamagnetic (less than 20 nanometers on an edge) or single-domain (20 to 100 nanometers). The magnetites within ALH84001 are typically 40 to 60 nanometers on an edge.

Single-domain magnetite has been reported in ancient terrestrial limestones and is generally regarded as having been produced by bacteria. Most intriguing, some of the magnetites in ALH84001 are arranged in chains, not unlike pearls in a necklace. Terrestrial bacteria often produce magnetite in precisely this pattern, because as they biologically process iron and oxygen from the water, they produce crystals that naturally align themselves with the Earth's magnetic field.

Organic Carbon Molecules

The presence of organic carbon molecules in ALH84001 constitutes the second group of clues. In recent years, researchers have found organic molecules not only in Martian meteorites but also in ones known to have come from the asteroid belt in interplanetary space, which could hardly support life. Nevertheless, the type and relative abundance of the specific organic molecules identified in ALH84001 are suggestive of life processes. The presence of indigenous organic molecules within ALH-84001 is the first proof that such molecules have existed on Mars.

On Earth, when living organisms die and decay, they create hydrocarbons associated with coal, peat and petroleum. Many of these hydrocarbons belong to a class of organic molecules known as polycyclic aromatic hydrocarbons (PAHs). There are thousands of different PAHs. Their presence in a sample does not in itself demonstrate that biological processes occurred. It is the location and association of the PAHs in the carbonate globules that make their discovery so interesting.

In ALH84001 the PAHs are always found in carbonate-rich regions, including the globules. In our view, the relatively simple PAHs are the decay products of living organisms that were carried by a fluid and trapped when the globules were formed. In 1996 a team at the Open University showed that the carbon in the globules in ALH84001 has an isotopic composition suggestive of microbes that used methane as a food source. If confirmed, this finding will be one of the strongest pieces of evidence to date that the rock bears the imprint of biological activity.

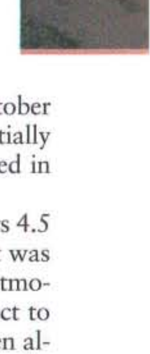
In our 1996 announcement, Richard N. Zare and Simon J. Clemett of Stanford used an extremely sensitive analytical technique to show that ALH84001 contains a relatively small number of different PAHs, all of which have been identified in the decay products of microbes. Most important, the PAHs were found to be located inside the meteorite, where contamination is very unlikely to have occurred. This crucial finding supports the idea that the carbonates are Martian and contain the vestiges of ancient living organisms.

PAHs are a component of automobile exhaust, and they have also been found in meteorites, planetary dust particles and even in interstellar space. Significantly, ultrasensitive analysis of the distribution of the PAHs in ALH84001 indicated that the PAHs could not have come from Earth or from an extraterrestrial source—other than Mars.

Perhaps the most visually compelling piece of evidence that at least vestiges of microbes came into contact with the rock are objects that appear to be the fossilized remains of microbes themselves. Detailed examination of the ALH-84001 carbonates using high-resolution scanning electron microscopy (SEM) revealed unusual features that are similar to those seen in terrestrial samples associated with biogenic activity. Close-up SEM views show that the carbonate globules contain ovoid and tube-shaped bodies [*see photomicrographs on preceding page*]. The objects are around 380 nanometers long, which means they could very well be the fossilized remains of bacteria. To pack in all the components that are normally required for a typical terrestrial bacterium to function, sizes larger than 250 nanometers seem to be required. Additional tubelike curved structures found in the globules are 500 to 700 nanometers in length.

Nanobacteria or Appendages?

Other objects found within ALH-84001 are close to the lower size limit for bacteria. These ovoids are only 40 to 80 nanometers long; other, tube-shaped bodies range from 30 to 170 nanometers in length and 20 to 40 nanometers in diameter. These sizes are about a factor of 10 smaller than the terrestrial microbes that are commonly recognized as bacteria. Still, typical cells often have appendages that are generally quite small—in fact about the same size as these features observed within ALH84001. It may be possible that some of the features are fragments or parts of larger units within the sample.



ALH84001's numerous ovoid and elongated features are essentially identical in size and morphology to those of so-called nanobacteria on Earth. So far little study has been devoted to nanobacteria or bacteria in the 20- to 400-nanometer range. But fossilized bacteria found within subsurface basalt samples from the Columbia River basin in Washington State [see "Microbes Deep inside the Earth," by James K. Fredrickson and Tullis C. Onstott; SCIENTIFIC AMERICAN, October 1996] have features that are essentially identical to some of those observed in the ovoids in ALH84001.

ALH84001 was present on Mars 4.5 billion years ago, when the planet was wetter, warmer and had a denser atmosphere. Therefore, we might expect to see evidence that the rock had been altered by contact with water. Yet the rock bears few traces of so-called aqueous alteration evidence. One such piece of evidence would be clay minerals, which are often produced by aqueous reactions. The meteorite does indeed contain phyllosilicate clay mineral, but only in trace amounts. It is not clear,

moreover, whether the clay mineral formed on Mars or in the Antarctic.

Mars had liquid water on its surface early in its history and may still have an active groundwater system below the permafrost or cryosphere. If surface microorganisms evolved during a period when liquid water covered parts of Mars, the microbes might have spread to subsurface environments when conditions turned harsh on the surface. The surface of Mars contains abundant basalts that were undoubtedly fractured during the period of early bombardment in the first 600 million years of the planet's history. These fractures could serve as pathways for liquid water and could have harbored any biota that were adapting to the changing conditions on the planet. The situation has an analogue on Earth, where thin gaps between successive lava flows appear to serve as aquifers for the movement and containment of groundwater containing living bacteria.

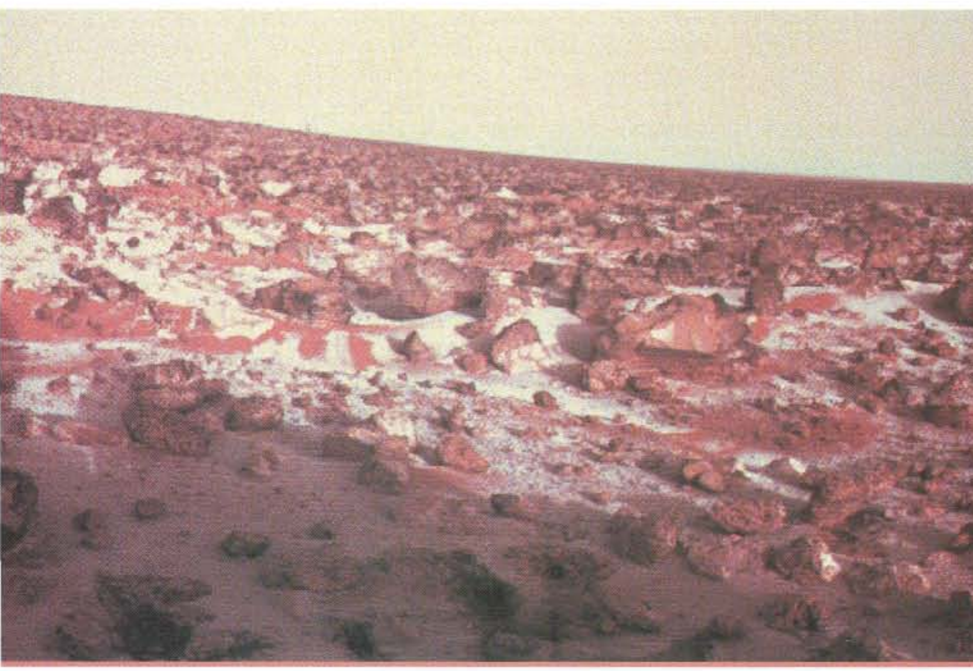
Organisms may also have developed at hot springs or in underground hydrothermal systems on Mars where chemical disequilibriums can be maintained in environments somewhat analogous to those of the mineral-rich "hot smokers" on the seafloor of Earth.

Thus, it is entirely possible that if organisms existed on Mars in the distant past, they may still be there. Availability of water within the pore spaces of a subsurface reservoir would facilitate their survival. If the carbonates within ALH-84001 were formed as early as 3.6 billion years ago and have biological origins, they may be the remnants of the earliest Martian life.

The analyses so far of ALH84001 are consistent with the meteorite's carbonate globules containing the vestiges of ancient microbial life. Studies of the meteorite are far from over, however. Whether or not these investigations confirm or modify our hypothesis, they will be invaluable learning experiences for researchers, who may get the opportunity to put the experience to use in coming years. We hope that in 2005 a "sample-return" mission will be launched to collect Martian rocks and soil robotically and return them to Earth two and a half years later. To take off from the Martian surface for the return to Earth, this revolutionary mission may use oxygen produced on the Martian surface by breaking down carbon dioxide in the planet's atmosphere.

Through projects such as the sample return, we will finally begin to collect the kind of data that will enable us to determine conclusively whether life came into being on Mars. This kind of insight, in turn, may ultimately provide perspective on one of the greatest scientific mysteries: the prevalence of life in our universe. SA

WATER FROST, probably only microns thick, covers parts of red, rocky Martian soil in a photograph taken by the Viking 2 lander in May 1979. The image was seen as further evidence that water exists on the surface of the planet, albeit in solid form.



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The Authors

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Williams Syndrome and the Brain

To gain fresh insights into how the brain is organized, investigators are turning to a little known disorder

by Howard M. Lenhoff, Paul P. Wang, Frank Greenberg and Ursula Bellugi

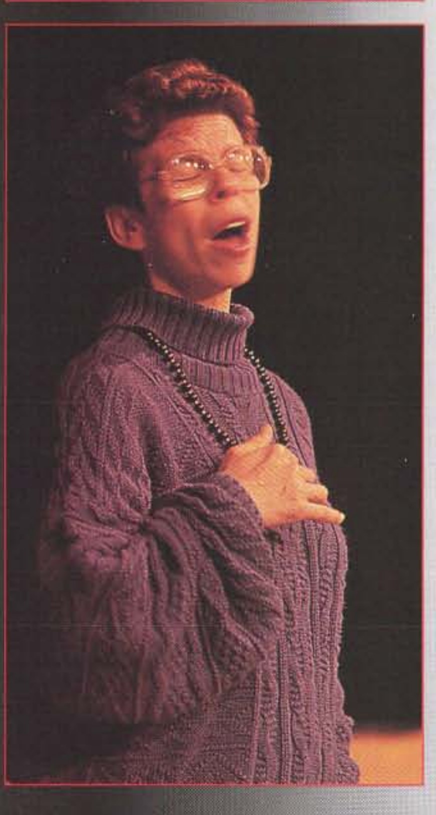
When a teenager with an IQ of just 49 was asked to draw an elephant and tell what she knew about the animal, her sketch was almost indecipherable. But her description was impressively rich, even lyrical. As part of that description, she noted, "It has long, gray ears, fan ears, ears that can blow in the wind...."

In her verbal ability, that young woman is fairly typical of people who have Williams syndrome, a rare condition that has recently started to draw the attention of a range of scientists. Affected individuals, sometimes called Williams people, are not all alike but often are similar to one another. They are frequently diagnosed as mildly to moderately "retarded" and generally score below average on standard IQ tests. They usually read and write poorly and struggle with simple arithmetic. Yet they display striking strengths in some realms. They generally demonstrate a facility not only for spoken language but also for recognizing faces. And, as a group, they tend to be empathetic, loquacious and sociable.

What is more, anecdotal evidence implies that some Williams people possess extraordinary musical talent. Even though their attention span for most tasks is short, many will listen to music, sing and play instruments with astonishing persistence. Most cannot read musical notes, yet some have perfect or nearly perfect pitch and an uncanny sense of rhythm. One boy quickly learned to play an extremely complex drumbeat in 7/4 time with one hand while drumming in 4/4 time with the other hand. A number of individuals retain complex music for years, remembering melodies and verses of long ballads; one even sings songs in 25 languages. Experienced Williams musicians also sing harmonies, improvise and compose lyrics readily.

Such anecdotes have recently led to the first systematic study of musical ability in Williams children. The results indicate that the youngsters discriminate melodies well; they also show significantly more interest in and emotional responsivity to music than do subjects from the general population. As one Williams child said, "Music is my favorite way of thinking."

Investigators are attracted to Williams syndrome in part because they suspect the dramatic peaks and valleys in the abilities of affected individuals will provide a new window to the organization and adaptability of the normal brain. Some groups are attempting to pinpoint characteristic properties of the Williams brain and to determine how those prop-



JESSICA BOYATT

PEOPLE WITH WILLIAMS SYNDROME display a striking mix of abilities and disabilities. For instance, when asked to draw and describe an elephant, an adolescent having an IQ of 49 produced a scribble that was incomprehensible without labels, yet she offered a rich verbal description (*opposite page*). Some individuals also display strong musical talent; this past summer those at the left—from top, Julia Tuttle, Brian Johnson and Gloria Lenhoff (daughter of author Howard M. Lenhoff)—attended a music and arts camp for Williams people, held at Belvoir Terrace in Lenox, Mass.

erties influence performance in intellectual and other realms. At the same time, researchers are trying to uncover the genetic abnormalities responsible for Williams syndrome.

In 1993 they learned that the disorder is caused by loss of a tiny piece from one of the two copies of chromosome 7 present in every cell of the body. The deleted piece can contain 15 or more genes. As the lost genes are identified, scientists can begin to determine how their absence leads to the neuroanatomical and behavioral features already observed. This integrated approach to the study of Williams syndrome—connecting genes to neurobiology and, ultimately, to behavior—may become a model for exploring how genes affect brain development and function.

Medical scientists are interested in Williams syndrome in its own right as well. Analysis of the genes in the deleted region has already explained why Williams people commonly suffer from certain physical ailments. It has also provided a means of prenatal testing and is helping to diagnose the disorder earlier, so that children who are affected can be helped from infancy to live up to their fullest potential; lack of familiarity with Williams syndrome in medical circles and the absence of reliable tests have hindered prompt diagnosis in the past.

Understanding Grew Slowly

Although Williams syndrome, which occurs in an estimated one in 20,000 births worldwide, has gained increased attention lately, it is not by any means new. An investigation by one of us (Lenhoff) suggests that Williams people were the inspiration for some age-old folktales about elves, pixies and other "wee people" [*see box on page 47*].

The medical community became aware of the syndrome fairly recently, however—only about 40 years ago. In 1961 J.C.P. Williams, a heart specialist in New Zealand, noted that a subset of his pediatric patients shared many characteristics. Beyond having related cardiovascular problems, they also had elfin facial features (such as a turned-up nose and a small chin) and seemed to be mentally retarded. The cardiac problems Williams observed often included heart murmurs and narrowing of major blood vessels. In particular, Williams people frequently suffer from supravalvular aortic stenosis (SVAS), a mild to severe constriction of the aorta.

Since that time, physicians have noted other traits, some of which can be seen quite early in life. In infancy, babies may have difficulty feeding and may suffer from stomach pains, constipation and hernias. They may also sleep poorly and can be irritable and colicky, behavior sometimes caused by another frequent sign: elevated amounts of calcium in the blood. As the children get older, they reveal hoarse voices and show delayed physical and mental development. They begin walking at an average of 21 months, often on the balls of their feet and usually with an awkwardness that persists throughout life. Fine motor control is disturbed as well. In addition, Williams people are extremely sensitive to noise, are often short compared with their peers and seem to age prematurely (for instance, their hair grays and their skin wrinkles relatively early).

Description began to give way to genetic understanding about four years ago, thanks in part to a study of SVAS in people who did not have Williams syndrome. In 1993 Amanda K. Ewart and Mark T. Keating of the University of Utah, Colleen A. Morris of the University of Nevada and other collaborators discovered that for a segment of this population, SVAS stemmed from an inherited mutation in one copy of the gene that gives rise to elastin—a protein that provides elasticity to many organs and tissues, such as the arteries, lungs, intestines and skin.

Missing Genes Are Identified

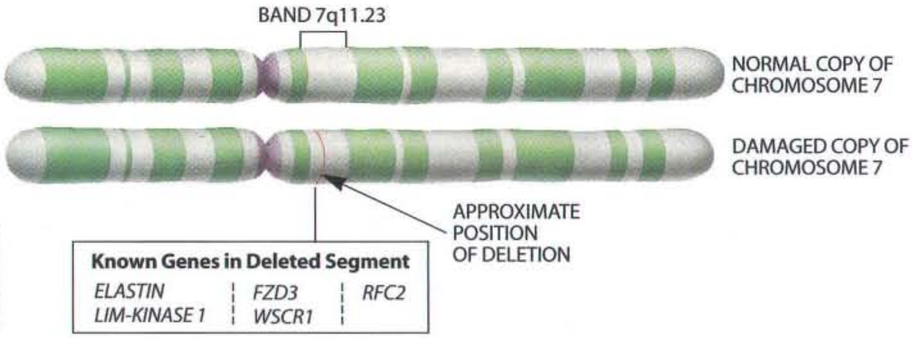
Aware that SVAS is common in Williams people and that individuals with familial SVAS alone and individuals with Williams syndrome both suffer disturbances in organs that require elasticity, the workers wondered whether Williams syndrome, too, involved some kind of change in the gene for elastin. Sure enough, they found the gene was deleted from one of the two copies of chromosome 7 in cells. Today it is evident that the deletion of the gene occurs in approximately 95 percent of patients with Williams syndrome. The loss is harmful presumably because both gene copies are needed to make adequate amounts of the elastin protein.

The investigators knew that a reduction in the elastin supply could contribute to various physical features of Wil-

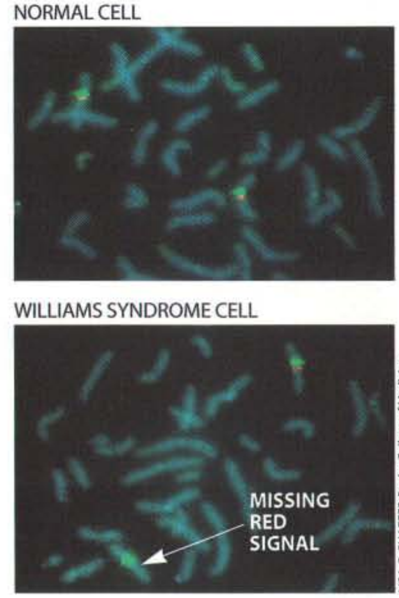
Drawing and Description of an Elephant by a Teen with Williams Syndrome

"What an elephant is, it is one of the animals. And what an elephant does, it lives in the jungle. It can also live in the zoo. And what it has, it has long, gray ears, fan ears, ears that can blow in the wind. It has a long trunk that can pick up grass or pick up hay. If they're in a bad mood, it can be terrible. If the elephant gets mad, it could stomp; it could charge. Sometimes elephants can charge. They have big long tusks. They can damage a car. It could be dangerous. When they're in a pinch, when they're in a bad mood, it can be terrible. You don't want an elephant as a pet. You want a cat or a dog or a bird."

COURTESY OF URSULA BELLUGI



TOMO NARASHIMA



LISA G. SHAFFER *Baylor College of Medicine*

TINY DELETION from one of the two copies of chromosome 7 in cells is the cause of Williams syndrome (*drawing*). The excised region can contain 15 or more genes, only some of which have been identified. A diagnostic test is based on the discovery that the gene for elastin is usually among those lost. The test flags copies of chromosome 7 with a fluorescent green tag and flags the gene for elastin with a fluorescent red tag. Chromosomes (*blue*) from a cell in a normal subject (*top micrograph*) will show two green and two red signals, indicating that both copies of chromosome 7 are present and that each carries the gene for elastin. But Williams people lack one copy of the gene, and so one copy of chromosome 7 will lack a red signal (*bottom micrograph*).

liams syndrome (such as SVAS, hernias and premature wrinkling), but it could not by itself account for the cognitive and behavioral signatures. After all, their first subjects, who had SVAS alone without cognitive impairment, would also have had low IQs if a diminution of elastin could unilaterally produce all the symptoms of Williams syndrome. This awareness led them to suspect that more genes were affected. In support of that idea, direct examinations of chromosomes from Williams patients indicated that the region deleted from chromosome 7 extended beyond the boundaries of the gene for elastin and probably encompassed many genes.

Several of those other genes are now being uncovered. Among them are three (*LIM-kinase 1*, *FZD3* and *WSCR1*) that are active in the brain—a sign that they could influence brain development and function. The exact activities carried out by the encoded proteins are not known, although Ewart and her colleagues have proposed that *LIM-kinase 1* (which is invariably deleted with the gene for elastin) may be involved in the ability to grasp spatial relationships. This role could help explain why Williams people have difficulty drawing simple common objects accurately from memory. Another gene from the deleted area, *RFC2*, specifies a protein involved in replication of DNA, but its contribution to Williams syndrome has not been established.

The genetic understanding of Williams syndrome is far from complete. Still, discovery of the deletion in chromosome 7 has yielded some practical rewards. That the deletion occurs in all cells of the body in Williams people tells mothers nothing they did or failed to do during pregnancy caused their child's condition. The disorder stems from a sperm or egg that, by chance, suffers a loss of genes from chromosome 7 before donating its chromosomes to the creation of an embryo. That knowledge also tells healthy siblings of Williams people that their copies of chromosome 7 are free of the deletion; therefore, any children they bear are no more likely than other children to acquire Williams syndrome. Finally, the microscopic technique that originally revealed the deletion of the gene for elastin—fluorescent in situ hybridization, or FISH—has now been adapted for use as a diagnostic tool.

A Cognitive Profile Emerges

Work on the genetics of Williams syndrome is complementing efforts to specify the neurobiological hallmarks of the disorder. That research, which today involves several laboratories, began about 15 years ago, when one of us (Bellugi) answered a late-night telephone call in her laboratory at the Salk Institute for Biological Studies in La Jolla, Calif. The caller knew that Bellugi investigated the neurobiological underpinnings of language and believed her daughter, who had Williams syndrome, would interest the Salk group. The girl, then 13, had an IQ near 50 and was considered mentally retarded. Consistent with that profile, she read and wrote at the level of a first grader. Yet she spoke beautifully.

Then, as now, scientists had difficulty distinguishing the brain processes controlling language from those controlling reasoning, because in the general population, adeptness at language and cognition usually go hand in hand. The dichotomy in the caller's daughter suggested that study of Williams people might help tease apart those processes.

Fascinated, Bellugi agreed to meet the girl and then continued to see her regularly. She also sought literature detailing the cognitive strengths and weaknesses of Williams people but found little beyond general assertions. Before Bellugi could hope to uncover the areas of the brain and the neurological processes that accounted for the unique cognitive characteristics of Williams people, she would need a finer-grained profile of the traits distinguishing that population from others. She and her colleagues therefore began to devise tests of specific abilities and to compare the scores of Williams people with those of the general population and of another cognitively impaired group: people with Down syndrome.

The investigations, which continue, examine populations of adolescents matched for sex, age and IQ level. (Williams people range in IQ from 40 to 100, but their mean score is about 60.) Early on, the team saw that Williams subjects, in contrast to their generally weak performance on overall tests of cognitive ability, commonly used well-formed grammar in their spontaneous speech. On the whole, they also performed significantly better than the group with Down syndrome did on all

tasks of grammatical comprehension and production.

Many also did well at the rather complex task of constructing tag questions, such as adding "doesn't she?" to the statement "Leslie likes fish." The person being tested must first take the original statement ("Leslie likes fish") and substitute a matching pronoun for the subject ("*She* likes fish"). Then the individual must add a conjugated auxiliary verb, negate it and contract it ("She *doesn't* like fish"), omit the original verb and object (leaving only "She doesn't") and invert the word order to form a question ("..., doesn't she?").

The Salk researchers further found, as others did later, that the Williams subjects frequently had vocabularies larger than would be expected for their mental age. When asked to list some animals, they often did not stick to easy words but chose such exotic examples as yak, Chihuahua, ibex, condor and unicorn.

Beyond possessing richer vocabularies, subjects with Williams syndrome tended to be more expressive than even normal children were. This animation was demonstrated amusingly when Williams children were asked to provide a story for a series of wordless pictures. As they told their tale, they often altered their pitch, volume, length of words or rhythm to enhance the emotional tone of the story. Similarly, they added more drama to engage their audience ("And suddenly, splash!"; "And BOOM!"; "Gadzooks!") than subjects with Down syndrome did. (Sadly, the gift of gab and sociability of Williams children can mislead teachers into thinking the children have better reasoning skills than they actually possess; in those cases, the children may not get the academic support they need.)

One possible explanation for the strong verbal performance of Williams individuals is that their chromosomal defect, in contrast to that of Down subjects, may not significantly disrupt certain faculties that support language processing. Other researchers, for instance, have reported that short-term memory for speech sounds, or "phonological working memory"—a form that seems to assist in language learning and comprehension—is relatively preserved in the Williams population.

Interestingly, recent studies of French and Italian Williams subjects suggest that one aspect of language known as morphology—the facet of grammar that deals with verb conjugation, gender assignment and pluralization—may not be completely preserved in Williams people. (These languages are much richer in morphology than English is.) This discovery implies that the brain regions preserved in Williams syndrome and the presence of an intact short-term memory for speech sounds support many verbal aptitudes but may not suffice for full mastery of language.

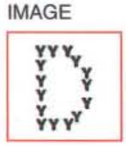
In contrast to their generally good showing on verbal tests, Williams subjects typically do poorly on tasks involving visual processing, such as copying drawings. But they often fail on such tasks in different ways than Down subjects do, suggesting that the deficits in the two groups may stem from differences in brain anatomy. For example, Williams people, in common with patients who have suffered a stroke in the right hemisphere of the brain, may attend to components of images but fail to appreciate the overall pattern (the gestalt). Down people, however, are more likely to perceive the global organization but to overlook many details [*see top illustration in box on this page*], just as individuals do who have suffered left-hemisphere strokes.

In some ways, the general profile revealed by the various cognitive tests im-

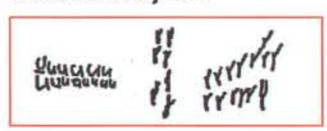
The Making of a Cognitive Profile

As part of an effort to pinpoint cognitive features that are characteristic of Williams people, investigators have compared subjects with Williams and with Down syndrome on tests of specific abilities. One test (*top*)—which asked adolescents to copy from memory a letter D that was built from a collection of small Y's—revealed impairment in integrating details into a larger configuration. The Williams group tended to draw only Y's, whereas the Down group tended to maintain the overall configuration but omit local details. Another test (*bottom*)—in which subjects had to invent a story for a series of wordless pictures—revealed that Williams people can often generate well-structured narratives.

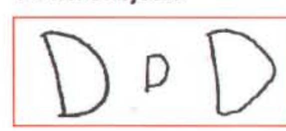
Task: REPRODUCE IMAGE



Williams subjects



Down subjects



COURTESY OF URSULA BELLUGI

Task: INVENT A STORY FOR THE PICTURES

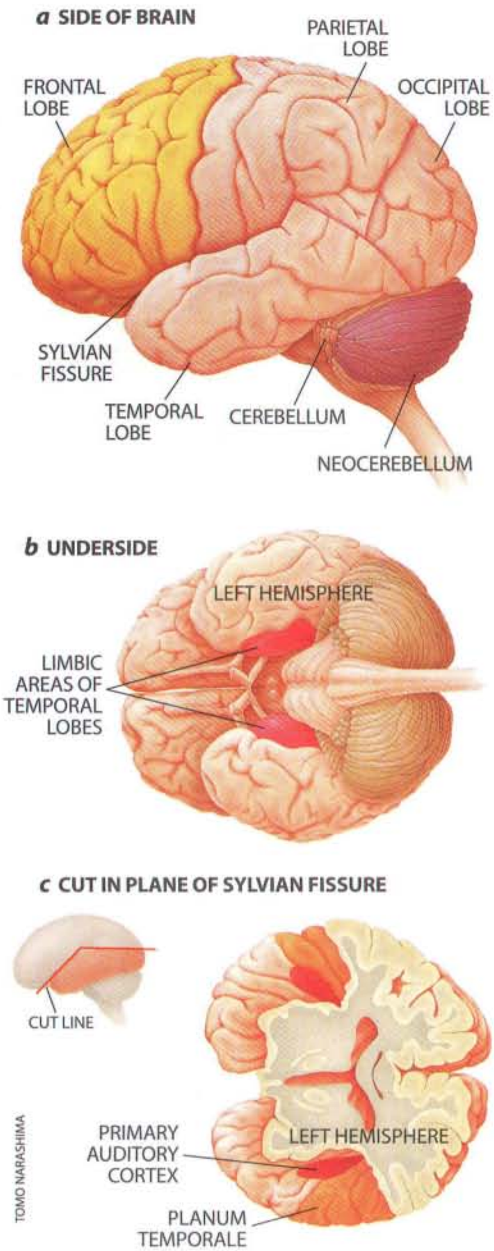
COURTESY OF PENGUIN PUTNAM, INC.

Williams subject, age 17, IQ 50

"Once upon a time when it was dark at night, the boy had a frog. The boy was looking at the frog, sitting on the chair, on the table, and the dog was looking through, looking up to the frog in a jar. That night he sleeped and slept for a long time, the dog did. But the frog was not gonna go to sleep. The frog went out from the jar. And when the frog went out, the boy and the dog were still sleeping. Next morning it was beautiful in the morning. It was bright, and the sun was nice and warm. Then suddenly when he opened his eyes, he looked at the jar and then suddenly the frog was not there. The jar was empty. There was no frog to be found."

Down subject, age 18, IQ 55

"The frog is in the jar. The jar is on the floor. The jar on the floor. That's it. The stool is broke. The clothes is laying there."



BASIC ANATOMY OF BRAIN in people with Williams syndrome is normal, but the total volume is somewhat reduced. The areas that seem to be best preserved include the frontal lobes and a part of the cerebellum called the neocerebellum (*a*), as well as parts of the temporal lobes known as the limbic area (*b*), the primary auditory area and the planum temporale (*c*).

plies that the chromosomal defect in Williams syndrome essentially spares the left hemisphere (the region most important to language in the large majority of people) and disrupts the right (the more visual-spatial hemisphere). But the emotional expressiveness of Williams people (also thought to be a right-sided function) and at least one other finding cast doubt on that simplistic view. Williams people recognize and discriminate among pictures of unfamiliar faces (a skill that requires the right hemisphere) remarkably well. In fact, they perform as well as adults from the general population.

Neurological Studies Add Clarity

The Salk group's examination of brains by magnetic resonance imaging and by autopsy supports the probability that the chromosomal deletion responsible for Williams syndrome alters the brain in a more complicated way. The deletion seems to produce anatomical changes (such as abnormal clustering of neurons in visual areas) that yield deficits in visual-spatial abilities. But the chromosomal defect appears to spare a network that includes structures in the frontal lobes, the temporal lobe and the cerebellum. This preserved network, then, may serve as a neuroanatomical scaffolding for the unexpectedly strong language abilities of Williams people.

To be more specific, the neuroanatomical studies indicate that the overall cortical volume in both Williams and Down people is smaller than that of age-matched normal subjects. But the volumes of individual regions differ between the two groups. For instance, the frontal lobes and the limbic region of the temporal lobes are better preserved in Williams people. The limbic system, which also includes other structures, is important for brain activities involving memory and emotions; sparing of the limbic region may help explain why Williams people are quite expressive and empathetic.

Analyses of the cerebellum uncovered further differences between the Williams and Down groups. Whereas its volume in Down subjects was small, that in Williams subjects was normal. And in Williams subjects the neocerebellum (considered to be the evolutionarily youngest region of the cerebellum) was equal to or larger than that in age-matched individuals in the general population but was reduced in Down subjects.

The finding that the neocerebellum is preserved in Williams people is particularly intriguing when placed in the context of other research. Until recently, the cerebellum was thought to be concerned primarily with movement. Yet Steven E. Petersen and his colleagues at Washington University have shown that the neocerebellum becomes active when subjects try to think of a verb that fits with a given noun (such as "sit" for "chair"). Further, tests of patients with cerebellar injuries reveal deficits in cognitive function, not just in motor abilities. And anatomists report that the neocerebellum communicates extensively with a part of the frontal cortex that, in common with the neocerebellum, is larger in humans than in apes.

Given that humans have language and apes do not, some observers have proposed that the neocerebellum and the connected region of the frontal cortex evolved together to support the fluent processing of speech and may fall under the control of the same genes. The relative preservation of the frontal cortex and the enlargement of the neocerebellum in Williams people, together with the rather spared fluency in language, lend some credence to this last notion and to the idea that the cerebellum plays a part in language processing.

Recent anatomical analyses have additionally identified features that could help explain the apparent musical talent of Williams people. The primary auditory cortex (located in the temporal lobe) and an adjacent auditory region, the planum temporale (thought to be important to language as well as musicality), are proportionately enlarged in the few Williams brains examined so far. In addition, the planum temporale is normally more extensive in the left hemisphere than in the right, but in some Williams people the left region is unusually big, to an extent characteristic of professional musicians. These findings mesh well with observations by Audrey Don of the University of Windsor in Ontario, the investigator who carried out the first studies of musical ability in Williams people. She concludes that intact perception of auditory patterns may account for much of the strength in music and language seen in Williams subjects—a result that implies the related brain structures should also be intact.

Physiological probes comparing electrical activity in the brains of Williams people and others during specific tasks offer more insights into how the brain develops. In response to grammatical stimuli, for example, normal subjects show greater activity from the left hemisphere than from the right, as would be expected for language tasks. But Williams people show symmetrical responses in the two hemispheres, a sign that the typical language specialization of the left hemisphere has not occurred. Fur-

Williams Syndrome: An Inspiration for Some Pixie Legends?

Folktales from many cultures feature magical "little people"—pixies, elves, trolls and other fairies. A number of physical and behavioral similarities suggest that at least some of the fairies in the early yarns were modeled on people who have Williams syndrome. Such a view is in keeping with the contention of historians that a good deal of folklore and mythology is based on real life.

The facial traits of Williams people are often described as pixielike. In common with pixies in folklore and art, many with Williams syndrome have small, upturned noses, a depressed nasal bridge, "puffy" eyes, oval ears and broad mouths with full lips accented by a small chin. Indeed, those features are so common that Williams children tend to look more like one another than their relatives, especially as children. The syndrome also is accompanied by slow growth and development, which leads most Williams individuals to be relatively short.

The "wee, magical people" of assorted folktales often are musicians and storytellers. Fairies are said to "repeat the songs they have heard" and can "enchant" humans with their melodies. Much the same can be said of people with Williams syndrome, who in spite of typically having subnormal IQs, usually display vivid narrative skills and often show talent for music. (The large pointed ears so often associated with fairies may symbolically represent the sensitivity of those mythical individuals—and of Williams people—to music and to sound in general.)

As a group, Williams people are loving, trusting, caring and extremely sensitive to the feelings of others. Similarly, fairies are frequently referred to as the "good people" or as kind and gentlehearted souls. Finally, Williams individuals, much like the fairies of legend, require order and predictability. In Williams people this need shows up as rigid adherence to daily routines and a constant need to keep abreast of future plans.

In the past, storytellers created folktales about imaginary beings to help explain phenomena that they did not understand—perhaps including the distinguishing physical and behavioral traits of Williams syndrome. Today researchers turn to Williams people in a quest to understand the unknown, hoping to decipher some of the secrets of how the brain functions. —*H.M.L.*

UNRELATED CHILDREN in the photograph above all display elfin facial features that clinicians associate with Williams syndrome. The depiction of an elf at the right is the 19th-century work of Richard Doyle, an uncle of the Sherlock Holmes creator.

ther, whereas normal adults generally show greater activity from the right hemisphere than the left when processing images of faces, Williams people show the opposite pattern. Such work favors the possibility that when normal developmental processes go awry, the brain often redistributes responsibilities, forming new circuits to carry out the functions of the disrupted ones.

Research into Williams syndrome is just now taking off, but it is already helping to clarify how the brain is organized. It is also making investigators see "mentally retarded" individuals in a new light. Close study of Williams syndrome has shown that low IQ scores can mask the existence of exciting capacities. And it warns that other so-called mentally retarded individuals could have untapped potentials waiting to be uncovered—if only researchers, and society, will take the trouble to look for and cultivate them. SA

The Authors

HOWARD M. LENHOFF, PAUL P. WANG, FRANK GREENBERG and URSULA BELLUGI offer several perspectives on Williams syndrome. Lenhoff is professor emeritus of biological sciences at the University of California, Irvine, the father of a 42-year-old Williams syndrome musician and co-organizer of the Williams Syndrome Music and Arts Camp, held in Massachusetts. He is also principal investigator of a team comparing music cognition in Williams people with other populations. Wang, assistant professor of pediatrics at the University of Pennsylvania School of Medicine, studies the neurobehavioral manifestations of Williams syndrome and other genetic disorders. Greenberg, clinical consultant with the National Center for Human Genome Research at the National Institutes of Health, has worked with Williams syndrome individuals for 20 years. Bellugi is director of the Laboratory for Cognitive Neurosciences at the Salk Institute for Biological Studies. She heads a multidisciplinary team that has been examining the cognitive, neuroanatomical and neurophysiological characteristics of Williams syndrome for more than a decade.

Further Reading

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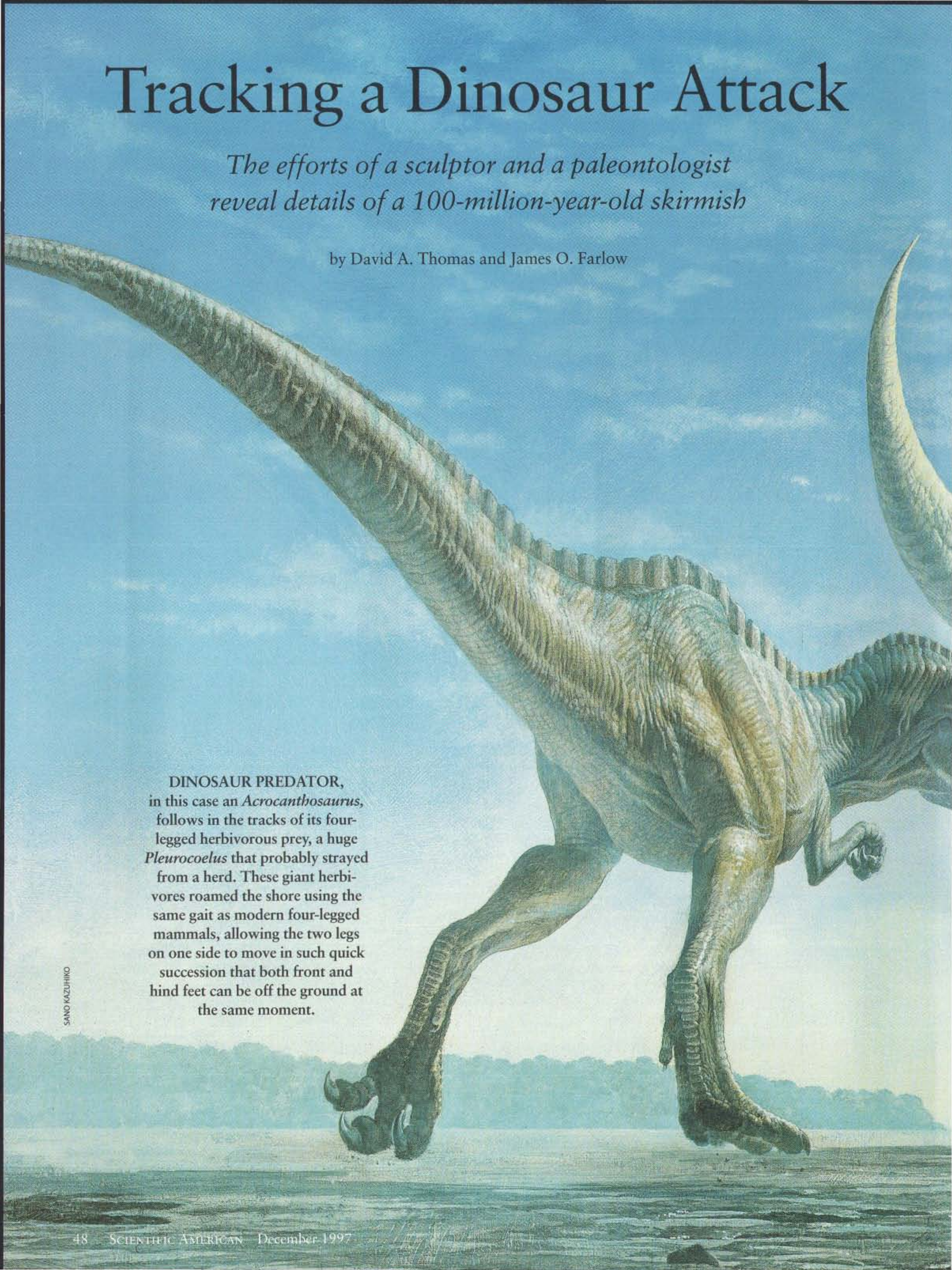
REAL-WORLD SOURCE FOR THE "LITTLE PEOPLE": THE RELATIONSHIP OF FAIRIES TO INDIVIDUALS WITH WILLIAMS SYNDROME. Howard M. Lenhoff in *Nursery Realms: Children in the Worlds of Science Fiction, Fantasy and Horror*. Edited by Gary Westfahl and George Slusser. University of Georgia (in press).

Tracking a Dinosaur Attack

The efforts of a sculptor and a paleontologist reveal details of a 100-million-year-old skirmish

by David A. Thomas and James O. Farlow



DINOSAUR PREDATOR, in this case an *Acrocanthosaurus*, follows in the tracks of its four-legged herbivorous prey, a huge *Pleurocoelus* that probably strayed from a herd. These giant herbivores roamed the shore using the same gait as modern four-legged mammals, allowing the two legs on one side to move in such quick succession that both front and hind feet can be off the ground at the same moment.

SANO KAZUHIKO

American paleontologists seeking dinosaur fossils made some notable finds in the years just before World War II. One of the excavations undertaken during this heyday produced no bones at all, but it nonetheless proved to be rich in information about dinosaurs. That dig, along the banks of the Paluxy River in central Texas, unearthed a dinosaur "trackway," a collection of footprints left on an ancient mudflat. Those fossilized impressions owe their preservation to the sediments that encased them, hardening and then eroding 100 million years later to reveal the wanderings of dinosaurs in now solid rock.

Dinosaur trackways of this kind are invaluable to paleontologists. Although there has been a great deal of speculation about dinosaur behavior, fossilized footprints provide the only direct evidence of how dinosaurs actually moved. By studying excavated trackways, paleontologists have been able to glean information about dinosaur gaits and postures. They have used such fossil footprints to determine how quickly different species walked and to deduce that many kinds of dinosaurs traveled in herds.

COURTESY OF ABC/KANE PRODUCTIONS

MODERN MAMMALS, such as these lions and Cape buffalo, show how predators often match stride with their prey before attacking. Soon after joining the hunt, the lion in the foreground easily picks up the cadence of the galloping buffalo: first the hind legs of the two animals move forward in synchrony (*a*), next the front legs (*b*) and then the hind legs again (*c*), just before the lion strikes at the rear of the buffalo (*d*).

One particularly intriguing observation from the Paluxy River trackway was made by Roland T. Bird, who discovered this curious set of dinosaur prints in 1938 and partially excavated them in 1940. Before cutting huge slabs of this footprint-studded rock to ship back to his employer, Barnum Brown of the American Museum of Natural History in New York City, Bird mapped and photographed the parallel tracks most thoroughly. He saw immediately that one set of footprints, from a two-footed carnivorous dinosaur (probably an *Acrocanthosaurus*, weighing perhaps two or three tons), ran parallel to the trail left by an even larger, four-footed herbivore (most likely a giant *Pleurocoelus*), which was apparently traveling in a herd. And he later noticed that the carnivorous dinosaur seemed at one point to have taken a strange skipping stride, leaving two consecutive right footprints in the mud.

Bird believed these two sets of footprints with a peculiar hop in the middle represented the moment the smaller carnivorous dinosaur struck at its larger herbivorous cousin. Most paleontologists with an interest in dinosaur tracks initially scoffed at that rather dramatic interpretation. But some now think Bird may have been correct. That revision in thinking came about because of an unlikely string of events that prompted us to reevaluate this decades-old find.

Digging Up Papers

Six years after Bird's death, in 1984, Texas Christian University undertook to publish Bird's autobiography, *Bones for Barnum Brown.* They contacted one of us (Farlow) to read the manuscript and to act as its scientific editor. And it came as a surprise that Bird's writing referred to various charts and a film of the excavation that paleontologists had not known existed.

AMERICAN MUSEUM OF NATURAL HISTORY

Interviews with Bird's wife and sister revealed that he had stashed away quite a bit of unpublished information about the Paluxy River trackway. Bird's nephew soon discovered a canister with the lost film of the excavation; it was neatly stored in a basement refrigerator. A box in Bird's attic provided countless notes, along with some large charts of the footprints in question. These diagrams were key finds, because the trackway had deteriorated considerably since 1940: not only were large pieces no longer in place (Bird sent slabs both to New York and to the Texas Memorial Museum in Austin), but seasonal flooding of the Paluxy River had eroded the rock surface and covered it with a mantle of sediment.

Fortunately, Bird's charts and photographs showed the placement of each of the prints in fine detail, enabling Farlow to study the site anew. That work resulted in an extensive report, published in 1987, which stated that the two parallel tracks represented one dinosaur following the other, just as Bird had originally surmised. But the interpretation of the strange hop remained open to debate within the community of professional dinosaur paleontologists—prompting a working artist to get involved.

Sculpting Science

In 1983 the city of Albuquerque commissioned one of us (Thomas) to produce a life-size dinosaur statue for the New Mexico Museum of Natural History and Science, a job that led to many further opportunities to cast dinosaurs in bronze and fiberglass for other museums around the world. To give those creations realistic stances, it was necessary to investigate how animals moved in general and how dinosaurs walked in particular.

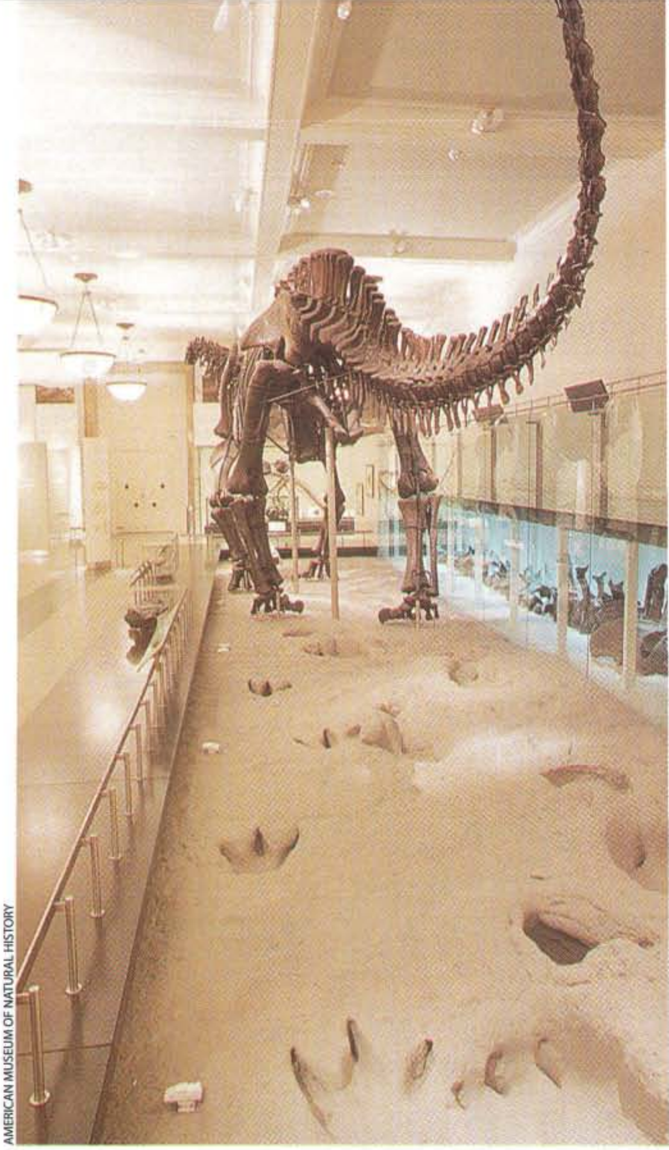
A quick study shows that a four-legged mammal, such as an elephant, routinely steps on its own tracks as it walks, with a rear foot often landing in the spot that the corresponding front foot has just vacated. It can do so because both feet on one side of the animal can be off the ground at once. But a modern reptile never places a rear foot exactly where its

front foot has trod. It walks with diagonal legs moving together, so the rear foot on one side lands before the front foot on that side leaves the ground.

Interestingly, the tracks of four-legged dinosaurs indicate that these creatures must have moved with gaits similar to those of living mammals and distinct from those used by most contemporary reptiles. This association is evident from the record unearthed from the banks of the Paluxy River: the four-footed herbivorous dinosaurs left imprints from their rear feet that commonly overlap their front footprints.

Might modern mammals have more to teach about the extinct reptiles that once roamed this ancient strand? In an effort to assess Bird's hypothesis, Thomas studied the way mammalian predators hunt. Attackers typically match the speed and direction of their game before they can strike. But often they do more. A carnivore on the attack will usually adjust its stride until it comes into exact rhythm with the running animal that it hopes to bring down.

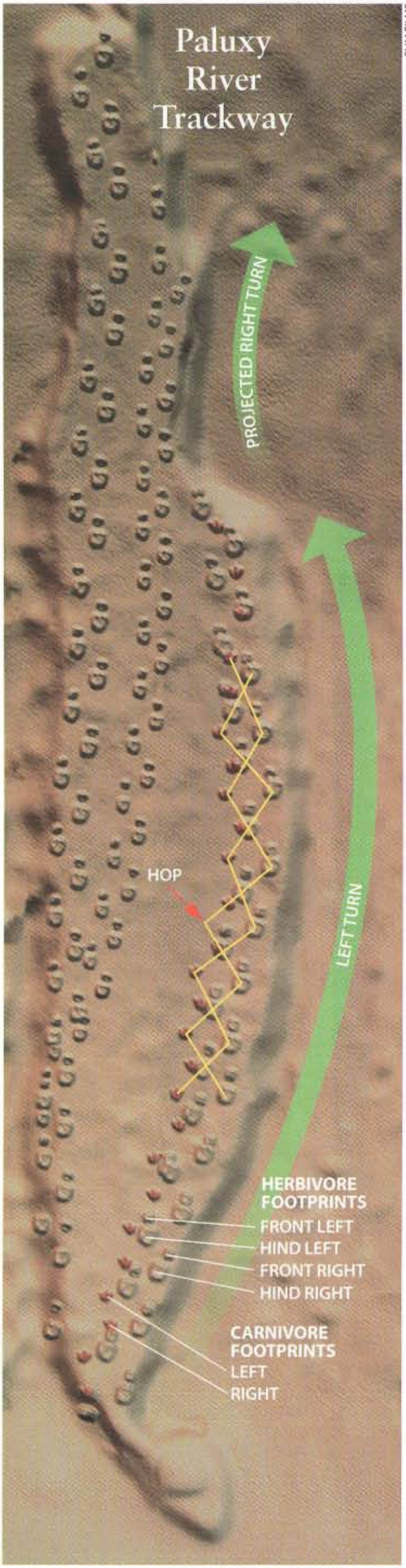
For example, a lion, cheetah or other swift cat will accelerate until it has caught up with its target. The predator then changes the length of its stride to match that of its prey. Only by keeping pace in this manner can the attacker reduce its motion relative to its quarry, which frequently is a much bulkier animal galloping furiously in an effort to escape. Eliminating relative motion is critical. Otherwise the predator would have difficulty striking safely and effectively when, finally, it lunges.



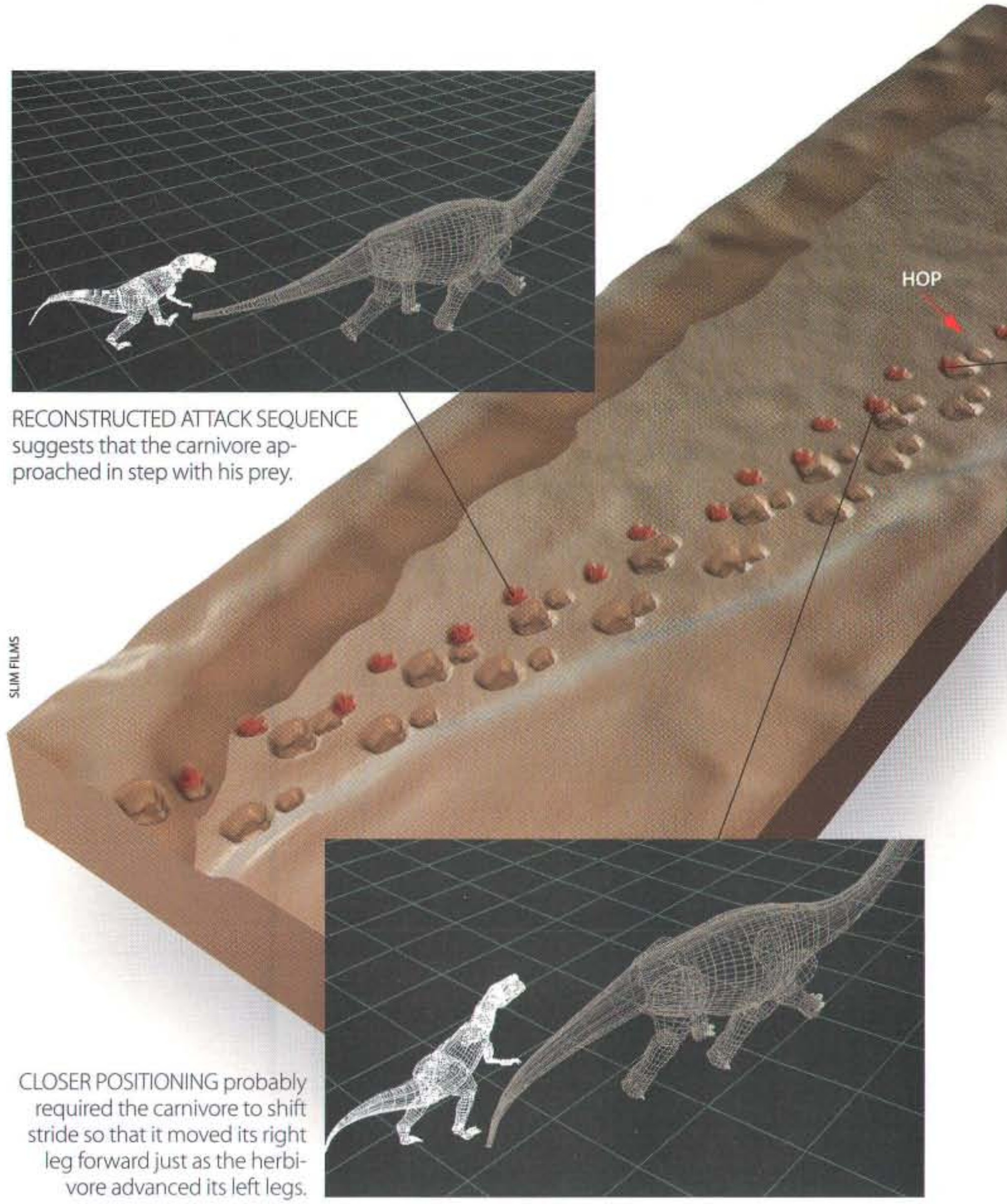
AMERICAN MUSEUM OF NATURAL HISTORY

STEVE RAWLS

FOSSIL IMPRINTS of the Paluxy River trackway were unearthed by Roland T. Bird and his co-workers in 1940 (*left*). A large slab taken from the excavation was sent to the American Museum of Natural History in New York City for exhibit (*top*), where it can still be seen by visitors. Bird also provided the Texas Memorial Museum in Austin with a segment of the trackway, one that contains a print showing a conspicuous drag mark (*bottom*) made by the four-legged herbivore, perhaps just after being struck.



SLIM FILMS



RECONSTRUCTED ATTACK SEQUENCE suggests that the carnivore approached in step with his prey.

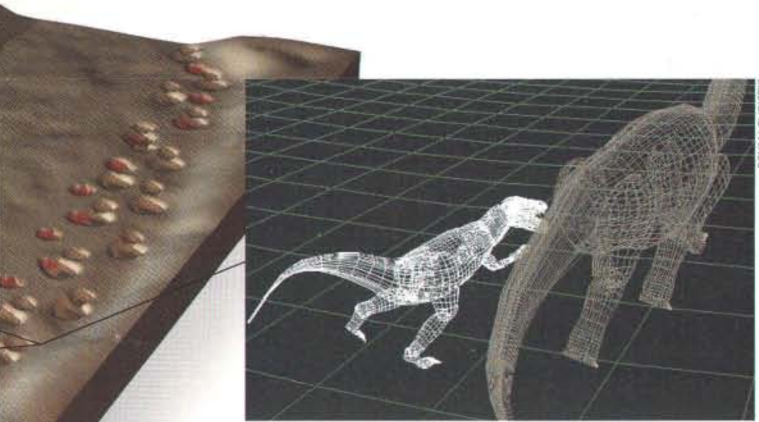
SLIM FILMS

CLOSER POSITIONING probably required the carnivore to shift stride so that it moved its right leg forward just as the herbivore advanced its left legs.

In an informal study of recorded attacks of various African predators (lions, leopards, cheetahs and hyenas), there proved to be only a few instances in which these animals clearly did not come into rhythm with their prey. Some of these exceptional occurrences involved an attacker executing a sudden ambush. In such cases, the need for surprise outweighs the desire to strike more carefully. Other examples in which the attacker failed to come into matching cadence were generally restricted to pairings of small prey and larger attackers, a combination for which it is neither practical nor necessary for the predator to harmonize its stride.

Some caution is clearly warranted in using these observations to help understand the fossilized Paluxy River tracks. After all, modern four-legged mammals are quite different from two- and four-legged dinosaurs. For instance, all the modern predators examined were in a gallop during the hunt, whereas the two-legged carnivorous dino-

BIRD'S CHART shows how the tracks of the two-legged carnivore (*red prints*) closely parallel one of several sets left by four-legged herbivores through a broad turn to the left. Both dinosaurs must also have veered right where the excavated tracks end, because their imprints do not cross the other two sets of tracks. The footprints of the predator and prey also show a remarkable symmetry for about a dozen paces (*yellow lines*), where it appears that they moved in synchrony—except for one point where the carnivore apparently hopped, leaving no left footprint (*red arrow*).


BRYAN CHRISTIE

APPARENT HOP (*two consecutive right footprints*) may mark the point on the trackway where the carnivore first struck at its prey.

saur in question was probably in a fast walk or slow run, and the four-legged herbivorous dinosaur was in a mammallike walk. Still, it would seem that in the early Cretaceous period, just as today, predators must have learned the advantages of matching rhythm with their prey.

100-Million-Year-Old Attack

One might imagine that the two dinosaurs under consideration had taken similar routes along what is now the Paluxy River simply because both were following the ancient shoreline, with their passages separated by many hours or even days. But detailed analysis of Bird's chart of the trackway shows that the proximity of the two sets of tracks could not have resulted from such happenstance.

Not only do the two trails run parallel, detailed examination reveals that the paths of the two animals wavered slightly and in the same fashion. So the subtle movements of one animal must have influenced the other. And something that is not seen at all provides additional evidence that the two sets of tracks were made at the same time. Near the end of the excavated lane, the tracks of the carnivore and herbivore both head toward the left. Had either animal continued in that direction, its footprints would have crossed into the adjacent sets of tracks. But they do not. Both animals must have turned right after leaving the area that Bird ultimately excavated. So, in all, the two trajectories make several jags and two broad turns together. These animals were undoubtedly interacting.

It indeed seems most likely that the carnivorous dinosaur was following the herbivore. The predator probably approached its prey from directly behind, lingering, at first, some steps back as it measured its quarry. The carnivore could then have come into rhythm by adjusting the length of its stride, just as mammals do today. Evidence for this behavior comes from a stretch of the trackway where the footprints for the two dinosaurs form an amazingly symmetrical array. For about a dozen steps, the carnivore placed its right foot near or into the print made by the left hind foot of the herbivore. This pattern is just what one would expect if the carnivore was trailing the herbivore as closely as possible without colliding—just a few steps back and slightly off to the left.

The rest of the scenario suggested by Bird—that the carnivore actually struck at its prey midway along the trackway—is more speculative, but there is good reason to believe it to be true. Hypothesizing an attack of this kind not only explains the uncanny similarity in the spacing of footprints between the two sets of tracks, it also accounts for the missing left footprint as a hop made by the carnivore, and it elucidates one additional piece of the puzzle unearthed more than half a century ago.

Bird's original observations show that the herbivore's right rear foot dragged at one point. This drag mark can be clearly seen in the slab housed at the Texas Memorial Museum. It occurs a few steps ahead of the spot where two consecutive right carnivore tracks occur. The mark suggests that the carnivore indeed hopped as it set upon the larger beast walking slightly ahead, because it makes sense that the animal struggling to escape would have faltered just as it was hit.

The drag mark and consecutive right footprints support the notion that the carnivore and herbivore moved over this patch of ground together, separated by only a few steps when the carnivore struck. And the location of these features points to a possibility that the herbivore attempted to carry out a defensive maneuver. It might have tried to throw its weight into the attacker just before being hit, exaggerating the defensive motion by turning left.

We do not know with certainty that such an attack or defense actually happened, how many carnivores joined the chase or why this particular herbivore was chosen to be culled from the herd. Too much of the record of this intriguing episode remains buried underground. But it now appears perfectly clear that about 100 million years ago, on a limey mudflat in what is now Texas, at least one swift carnivore singled out and possibly attacked a huge, lumbering herbivore. It seems that Bird was not only lucky enough to find remarkable evidence of this incident of natural history but that he was also wise enough to recognize, document and excavate part of the record of this ancient hunt left on a sodden plain, now turned to stone. SA

The Authors

DAVID A. THOMAS and JAMES O. FARLOW came to examine these dinosaur tracks after following very different career paths. Thomas, a sculptor, cast the world's first life-size bronze statue of a dinosaur in 1985 for the New Mexico Museum of Natural History and Science in Albuquerque. Some of Thomas's other dinosaur creations are displayed at the Anniston Museum of Natural History in Alabama, the College of Eastern Utah Museum and the National Museum of Natural Science of Taiwan. His desire to make these statues technically accurate led him into the study of animal gaits and tracks. Farlow, a paleontologist, received a doctorate from Yale University in 1980. He is now a professor of geology at Indiana-Purdue University at Fort Wayne, where he does research on dinosaur footprints and biology and on Ice Age mammals of the midwestern U.S.

Further Reading

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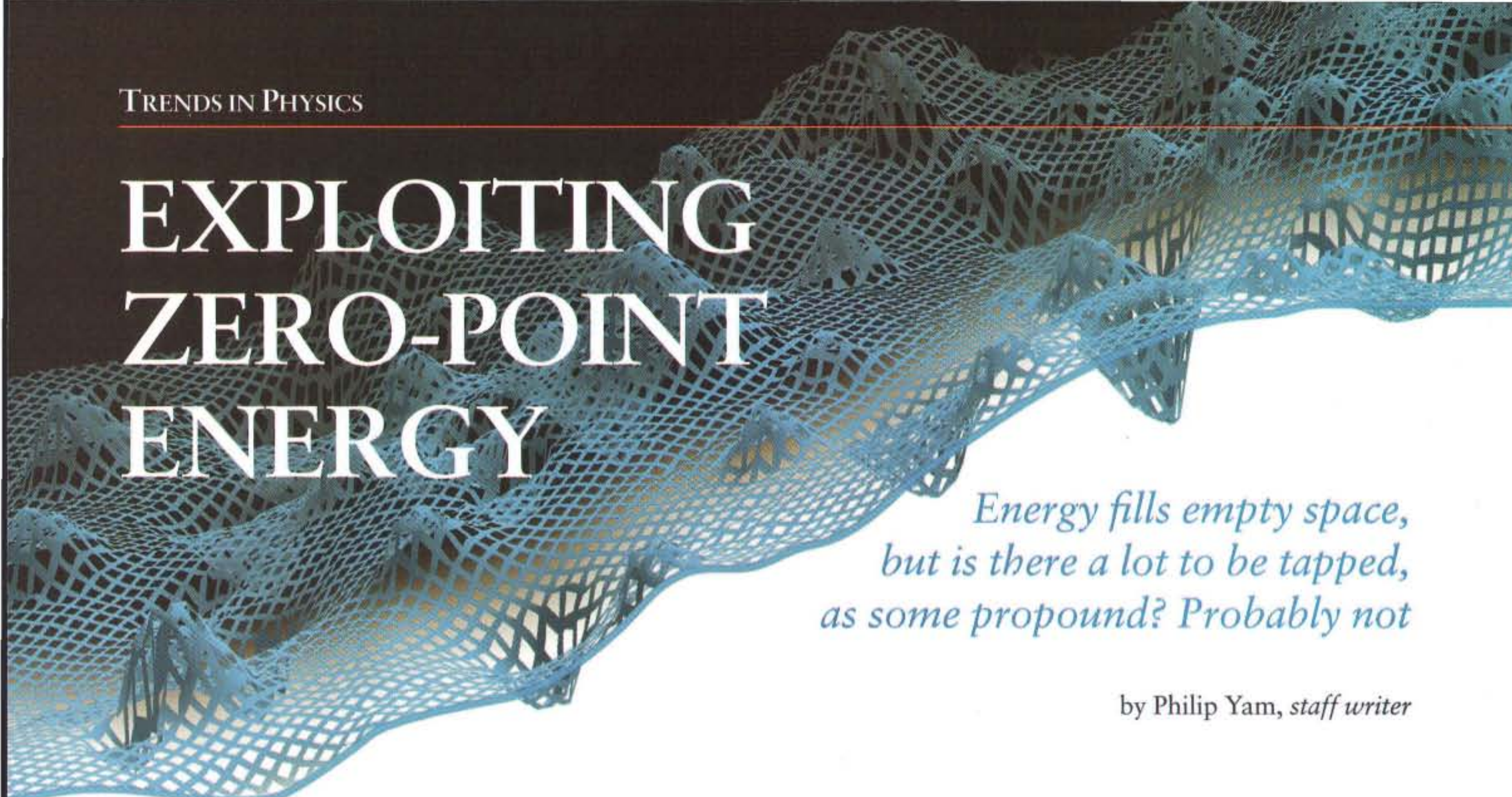


EXPLOITING ZERO-POINT ENERGY

Energy fills empty space, but is there a lot to be tapped, as some propound? Probably not

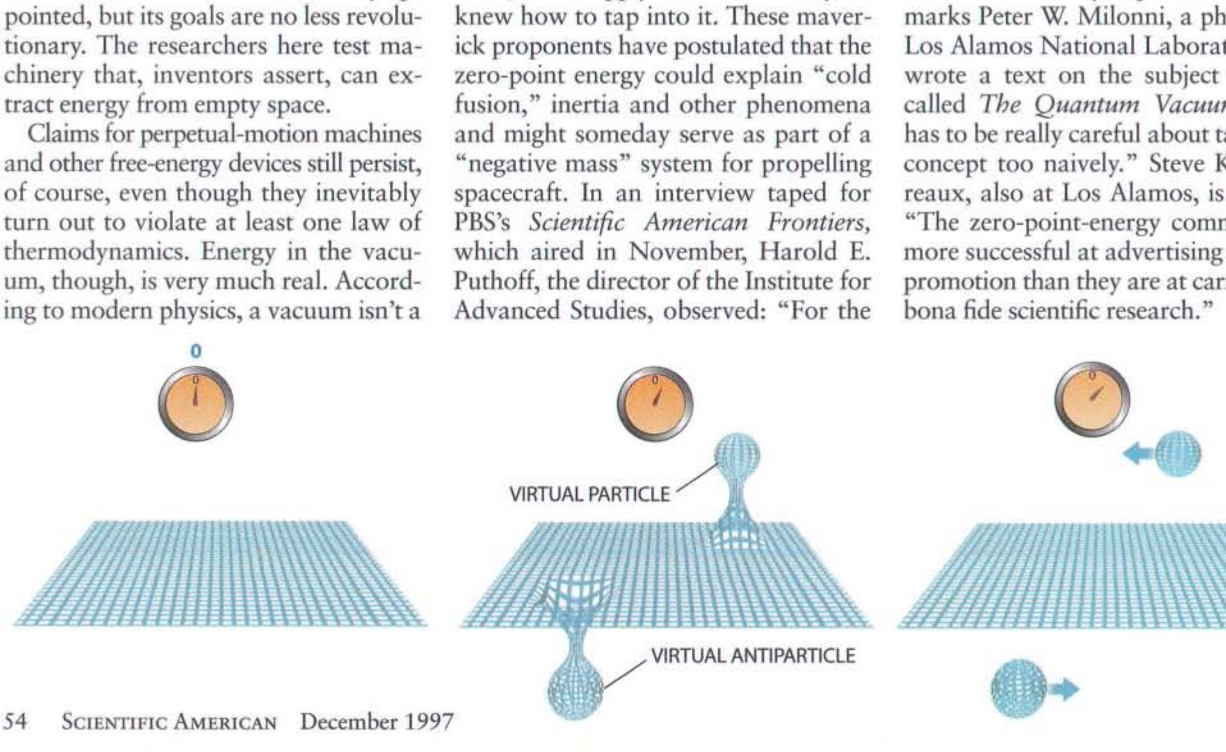
by Philip Yam, *staff writer*

Something for nothing. That's the reason for the gurgling water, ultrasonic transducers, heat-measuring calorimeters, data-plotting software and other technological trappings—some seemingly of the backyard variety—inside the Institute for Advanced Studies in Austin, Tex. One would not confuse this laboratory with the similarly named but far more renowned one in Princeton, N.J., where Albert Einstein and other physicists have probed fundamental secrets of space and time. The one in Austin is more modestly appointed, but its goals are no less revolutionary. The researchers here test machinery that, inventors assert, can extract energy from empty space.

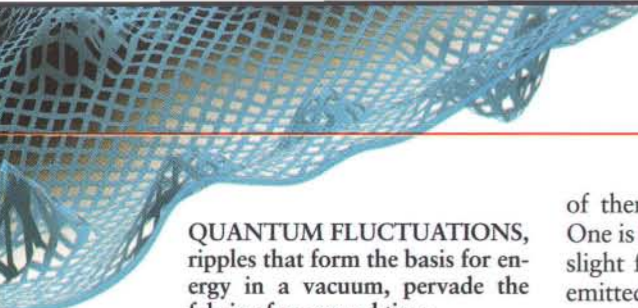
Claims for perpetual-motion machines and other free-energy devices still persist, of course, even though they inevitably turn out to violate at least one law of thermodynamics. Energy in the vacuum, though, is very much real. According to modern physics, a vacuum isn't a pocket of nothingness. It churns with unseen activity even at absolute zero, the temperature defined as the point at which all molecular motion ceases.

Exactly how much "zero-point energy" resides in the vacuum is unknown. Some cosmologists have speculated that at the beginning of the universe, when conditions everywhere were more like those inside a black hole, vacuum energy was high and may have even triggered the big bang. Today the energy level should be lower. But to a few optimists, a rich supply still awaits if only we knew how to tap into it. These maverick proponents have postulated that the zero-point energy could explain "cold fusion," inertia and other phenomena and might someday serve as part of a "negative mass" system for propelling spacecraft. In an interview taped for PBS's *Scientific American Frontiers,* which aired in November, Harold E. Puthoff, the director of the Institute for Advanced Studies, observed: "For the chauvinists in the field like ourselves, we think the 21st century could be the zero-point-energy age."

That conceit is not shared by the majority of physicists; some even regard such optimism as pseudoscience that could leech funds from legitimate research. The conventional view is that the energy in the vacuum is minuscule. In fact, were it infinite, the nature of the universe would be vastly different: you would not be able to see in a straight line beyond a few kilometers. "The vacuum has some mystique about it," remarks Peter W. Milonni, a physicist at Los Alamos National Laboratory who wrote a text on the subject in 1994 called *The Quantum Vacuum.* "One has to be really careful about taking the concept too naively." Steve K. Lamoreaux, also at Los Alamos, is harsher: "The zero-point-energy community is more successful at advertising and self-promotion than they are at carrying out bona fide scientific research."



ILLUSTRATIONS BY MICHAEL GOODMAN



QUANTUM FLUCTUATIONS, ripples that form the basis for energy in a vacuum, pervade the fabric of space and time.

The concept of zero-point energy derives from a well-known idea in quantum mechanics, the science that accounts for the behavior of particles near the atom's size. Specifically, zero-point energy emerges from Heisenberg's uncertainty principle, which limits the accuracy of measurements. The German physicist Werner Heisenberg determined in 1927 that it is impossible to learn both the position and the momentum of a particle to some high degree of accuracy: if the position is known perfectly, then the momentum is completely unknown, and vice versa. That's why at absolute zero, a particle must still be jittering about: if it were at a complete standstill, its momentum and position would both be known precisely and simultaneously, violating the uncertainty principle.

Energy and Uncertainty

Like position and momentum, energy and time also obey Heisenberg's rule. Residual energy must therefore exist in empty space: to be certain that the energy was zero, one would have to take energy measurements in that volume of space forever. And given the equivalence of mass and energy expressed by Einstein's $E = mc^2$, the vacuum energy must be able to create particles. They flash briefly into existence and expire within an interval dictated by the uncertainty principle.

This zero-point energy (which comes from all the types of force fields—electromagnetic, gravitational and nuclear) makes itself felt in several ways, most of them obvious only to a physicist. One is the Lamb shift, which refers to a slight frequency alteration in the light emitted by an excited atom. Another is a particular kind of inescapable, low-level noise that registers in electronic and optical equipment.

Perhaps the most dramatic example, though, is the Casimir effect. In 1948 the Dutch physicist H.B.G. Casimir calculated that two metal plates brought sufficiently close together will attract each other very slightly. The reason is that the narrow distance between the plates allows only small, high-frequency electromagnetic "modes" of the vacuum energy to squeeze in between. The plates block out most of the other, bigger modes. In a way, each plate acts as an airplane wing, which creates low pressure on one side and high pressure on the other. The difference in force knocks the plates toward each other.

While at the University of Washington, Lamoreaux conducted the most precise measurement of the Casimir effect. Helped by his student Dev Sen, Lamoreaux used gold-coated quartz surfaces as his plates. One plate was attached to the end of a sensitive torsion pendulum; if that plate moved toward the other, the pendulum would twist. A laser could measure the twisting of the pendulum down to 0.01-micron accuracy. A current applied to a stack of piezoelectric components moved one Casimir plate; an electronic feedback system countered that movement, keeping the pendulum still. Zero-point-energy effects showed up as changes in the amount of current needed to maintain the pendulum's position. Lamoreaux found that the plates generated about 100 microdynes (one nanonewton) of force. That "corresponds to the weight of a blood cell in the earth's gravitational field," Lamoreaux states. The result falls within 5 percent of Casimir's prediction for that particular plate separation and geometry.

Zero for Zero-Point Devices

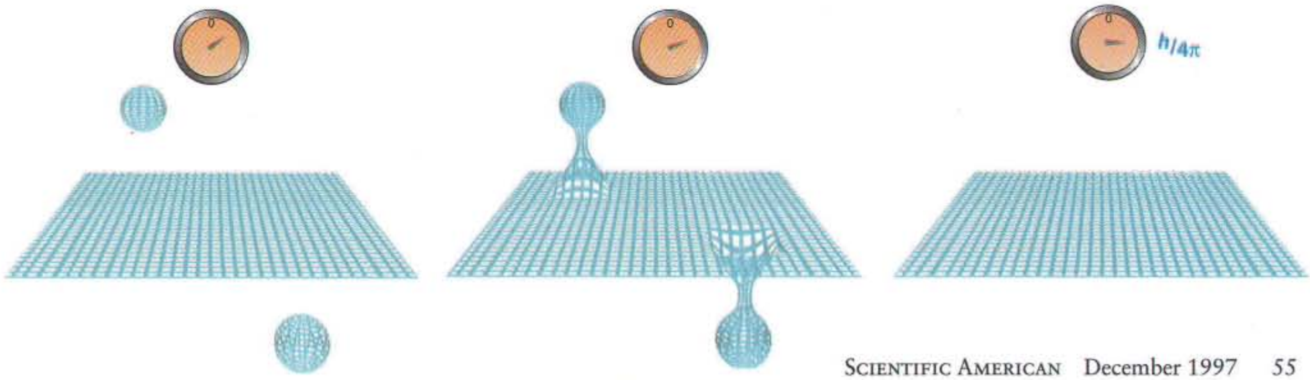
Demonstrating the existence of zero-point energy is one thing; extracting useful amounts is another. Puthoff's institute, which he likens to a mini Bureau of Standards, has examined about 10 devices over the past 10 years and found nothing workable.

One contraption, whose Russian inventor claimed could produce kilowatts of excess heat, supposedly relied on sonoluminescence, the conversion of sound into light. Bombarding water with sound to create air bubbles can, under the right conditions, lead to bubbles that collapse and give off flashes of light. Conventional thinking explains sonoluminescence in terms of a shock wave launched within the collapsing bubble, which heats the interior to a flash point.

Following up on the work of the late Nobelist Julian Schwinger, a few workers cite zero-point energy as the cause. Basically, the surface of the bubble is supposed to act as the Casimir force plates; as the bubble shrinks, it starts to exclude the bigger modes of the vacuum energy, which is converted to light. That theory notwithstanding, Puthoff and his colleague Scott Little tested the device and changed the details a number of times but never found excess energy.

Puthoff believes atoms, not bubbles, offer a better approach. His idea hinges

VIRTUAL PARTICLES can spontaneously flash into existence from the energy of quantum fluctuations. The particles, which arise as matter-antimatter twins, can interact but must, in accordance with Heisenberg's uncertainty principle, disappear within an interval set by Planck's constant, *h*.



on an unproved hypothesis: that zero-point energy is what keeps electrons in an atom orbiting the nucleus. In classical physics, circulating charges like an orbiting electron lose energy through radiation; what keeps the electron zipping around the nucleus is, to Puthoff, zero-point energy that the electron continuously absorbs. (Quantum mechanics as originally formulated simply states that an electron in an atom must have some minimum, ground-state energy.)

Physicists have demonstrated that a small enough cavity can suppress the natural inclination of a trapped, excited particle to give up some energy and drop to a lower energy state [see "Cavity Quantum Electrodynamics," by Serge Haroche and Jean-Michel Raimond; SCIENTIFIC AMERICAN, April 1993]. Basically, the cavity is so small that it can exclude some of the lower-frequency vacuum fluctuations, which the excited atom needs to emit light and drop to a lower energy level. The cavity in effect controls the vacuum fluctuations.

Under the right circumstances, Puthoff reasons, one could effectively manipulate the vacuum so that a new, lower ground state appears. The electron would then drop to the lower ground state—in effect, the atom would become smaller—and give up some energy in the process. "It implies that hydrogen or deuterium injected into cavities might produce excess energy," Puthoff says. This possibility might explain cold-fusion experiments, he notes—in other words, the occasional positive results reported in cold-fusion tests might really be indicators of zero-point energy (rather than, one would assume, wishful thinking).

Work in cavity quantum electrodynamics is experimentally challenging in its own right, however, so it is not clear how practical an energy supply from "shrinking atoms" could be. The Austin institute is testing a device that could be interpreted as manipulating the vacuum, although Puthoff declines to provide details, citing proprietary nondisclosure agreements with its designers.

How Much in Nothing?

Underlying these attempts to tap the vacuum is the assumption that empty space holds enough energy to be tapped. Considering just the fluctuations in the electromagnetic force, the mathematics of quantum mechanics suggest that any given volume of empty space could contain an infinite number of vacuum-energy frequencies—and hence, an infinite supply of energy. (That does not even count the contributions from other forces.) This sea of energy is largely invisible to us, according to the zero-point-energy chauvinists, because it is completely uniform, bombarding us from all directions such that the net force acting on any object is zero.

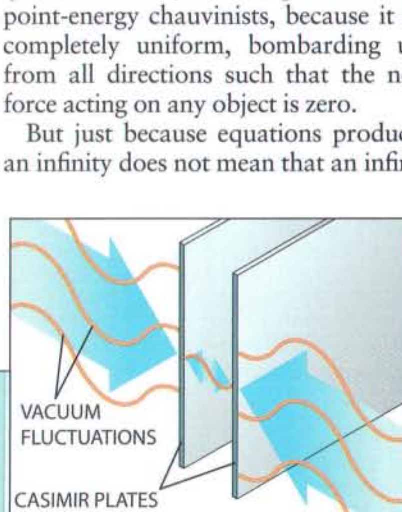
But just because equations produce an infinity does not mean that an infinity exists in any practical sense. In fact, physicists quite often "renormalize" equations to get rid of infinities, so that they can ascribe physical meaning to their numbers. An example is the calculation of the electron's mass from theoretical principles, which at face value leads to an unrealistic, infinite mass. The same kind of mathematical sleight-of-hand might need to be done for vacuum-energy calculations. "Somehow the notion that the energy is infinite is too naive," Milonni says.

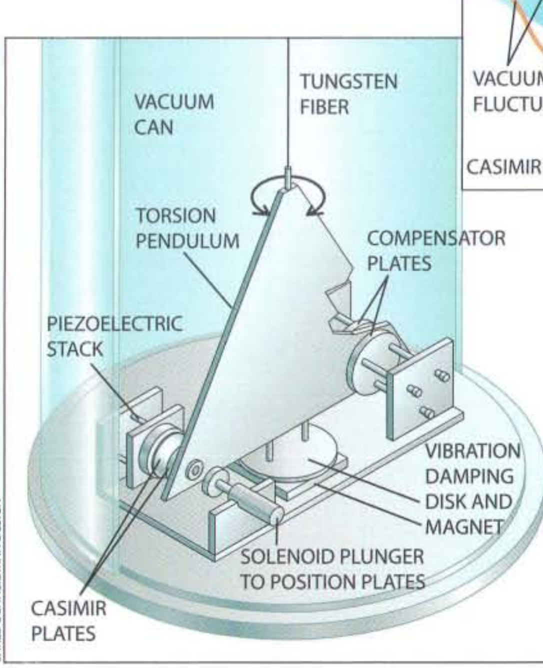
In fact, several signs indicate that the amount of energy in the vacuum isn't worth writing home about. Lamoreaux's experiment could roughly be considered to have extracted 10^{-15} joule. That paltry quantity would seem to be damning evidence that not much can be extracted from empty space. But Puthoff counters that Casimir plates are macroscopic objects. What is needed for practical energy extraction are many plates, say, some 10^{23} of them. That might be possible with systems that rely on small particles, such as atoms. "What you lose in energy per interaction, you gain in the number of interactions," he asserts.

Milonni replies by noting that Lamoreaux's plates themselves are made of atoms, so that effectively there were 10^{23} particles involved. The low Casimir result still indicates, by his figures, that the plates would need to be kilometers long to generate even a kilogram of force. Moreover, there is a cost in extracting the energy of the plates coming together, Milonni says: "You have to pull the plates apart, too."

Another argument for a minuscule vacuum energy is that the fabric of space and time, though slightly curved near objects, is pretty much flat overall. Draw a triangle in space and the sum of its angles is 180 degrees, as it would be on a flat piece of paper. (The angles of a triangle on a sphere, conversely, sum to more than 180 degrees.) Because energy is equivalent to matter, and matter exerts a gravitational force, cosmologists expect that an energy-rich vacuum would create a strong gravity field that distorts space and time as it is seen today. The whole universe would be evolving in a different manner.

That argument ties into

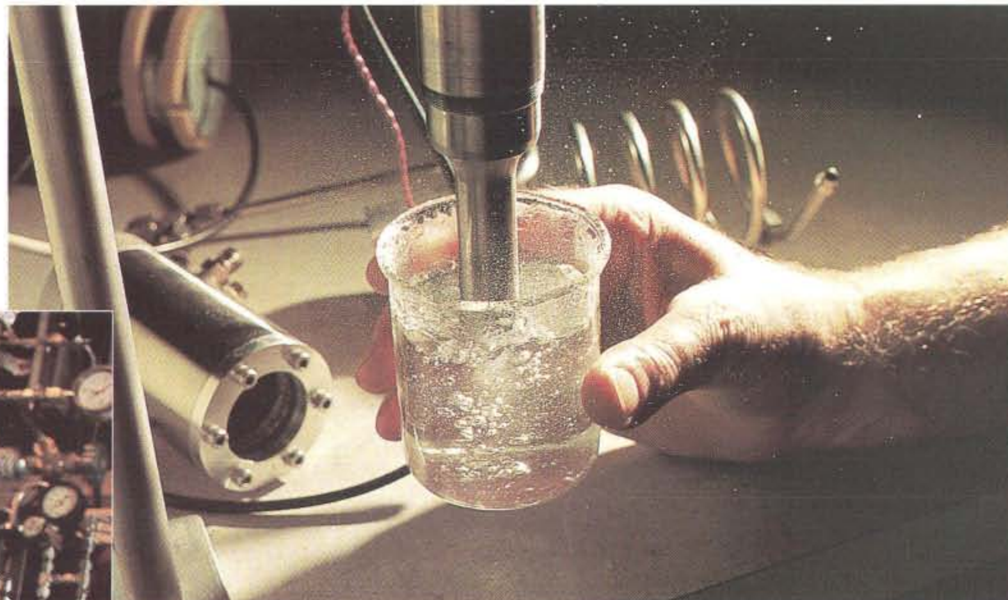


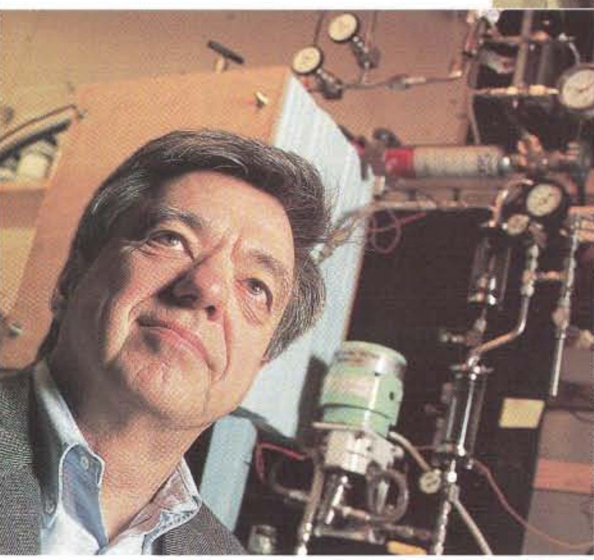


JARED SCHNEIDMAN DESIGN

CASIMIR EFFECT is the motion of two parallel plates because of quantum fluctuations in a vacuum. The plates are so close together that only small fluctuations fit in between; the bigger modes are excluded (*above*). They exert a total force greater than that by the smaller modes and hence push the plates together. The effect was observed by Steve K. Lamoreaux, now at Los Alamos National Laboratory, who relied on a torsion pendulum (*left*). A current applied to the piezoelectric stack tried to move the Casimir plate on the pendulum; the compensator plates held the pendulum still. The voltage needed to prevent any twisting served as a measure of the Casimir effect.

ZERO-POINT ENERGY was purportedly tapped with a machine that made use of ultrasonically generated bubbles (*right*). Such devices are tested by Harold E. Puthoff (*below*), director of the Institute for Advanced Studies in Austin, Tex. So far no apparatus has been found to produce a net gain in energy.





PHOTOGRAPHS BY WILL VAN OVERBEEK

the cosmological constant, a concept that Einstein first developed, then discarded. In the equations that describe the state of the universe, the cosmological constant—which incorporates zero-point energy—is in a sense a term that can counteract gravity. Astronomical observations suggest the constant must be nearly zero. Consequently, if the vacuum energy really is large, then some other force that contributes to the constant must offset it. And as physicist Steven Weinberg of the University of Texas notes in his 1992 book *Dreams of a Final Theory,* that offset feels unnatural: calculations that sidestep the infinity terms produce a vacuum energy 120 orders of magnitude greater than the nearly zero value of the cosmological constant, so that other force must be opposite but identical in magnitude to the vacuum energy out to 120 decimal places.

Puthoff replies that the connection between the cosmological constant and zero-point energy is more complex than is often realized. "Obviously, the zero-point-energy problem and the cosmological constant, though related, are really different problems," Puthoff argues, noting that predictions of quantum mechanics have proved correct time and again and that instead something is still missing from cosmologists' thinking.

Such disagreements in science are not unusual, especially considering how little is really known about zero-point energy. But those would-be utility moguls who think tapping zero-point energy is a worthwhile pursuit irritate some mainstream scientists. "I was rather dismayed at the attention from what I consider a kook community," Lamoreaux says of his celebrity status among zero-point aficionados after publishing his Casimir effect result. "It trivializes and abuses my work." More galling, though, is that these "pseudoscientists secure funding, perhaps governmental, to carry on with their research," he charges.

Puthoff's institute receives a little government money but gets most of its funds from contracts with private firms. Others are backed more explicitly by public money. This past August the National Aeronautics and Space Administration sponsored a meeting called the "Breakthrough Propulsion Physics Workshop." According to participants, zero-point energy became a high priority among those trying to figure out which "breakthroughs" should be pursued.

The propulsion application depends on a speculation put forth in 1994 by Puthoff, Bernhard Haisch of Lockheed Palo Alto Research Laboratory and Alfonso Rueda of California State University at Long Beach. They suggested that inertia—the resistance that objects put up when they are accelerated—stems from the drag effects of moving through the zero-point field. Because the zero-point field can be manipulated in quantum experiments, Puthoff reasons, it should be possible to lessen an object's inertia and hence, for a rocket, reduce the fuel burden. Puthoff and his colleagues have been trying to prove this inertia-origin hypothesis—a sensitive pendulum should be able to detect a zero-point-energy "wake" left by a moving object—but Puthoff says they have not managed to isolate their system well enough to do so.

More conventional scientists decried the channeling of NASA funds to a meeting where real science was lacking. "We hardly talked about the physics" of the proposals, complained Milonni, adding that during one of the breakout sessions "there was a guy talking about astral projection."

Certainly, there should be room for far-out, potentially revolutionary ideas, but not at the expense of solid science. "One has to keep an open mind, but the concepts I've seen so far would violate energy conservation," Milonni concludes. In sizing up zero-point-energy schemes, it may be best to keep in mind the old caveat emptor: if it sounds too good to be true, it probably is. SA

Further Reading

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SPECIAL REPORT

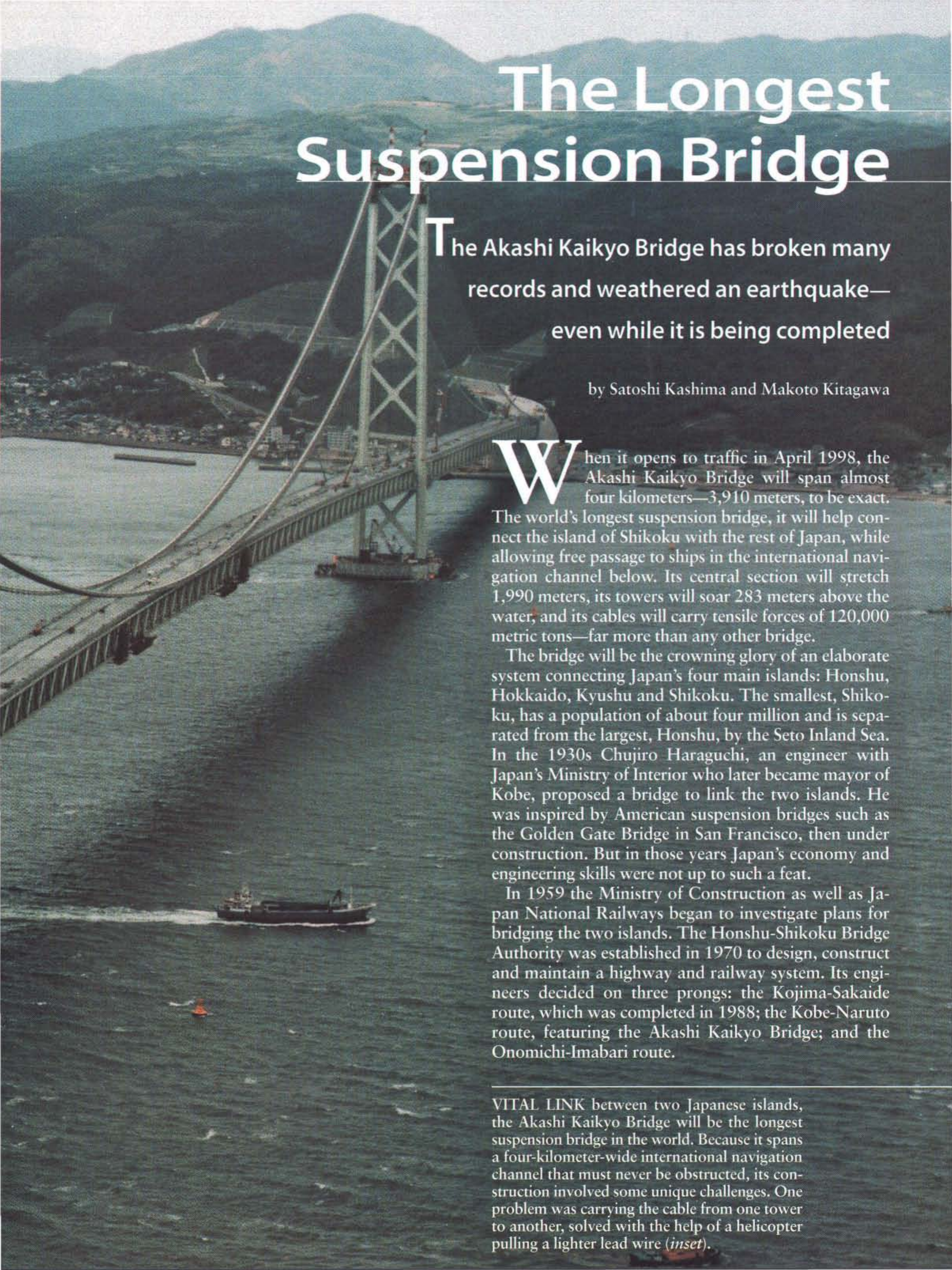
Building the Biggest

TIM DUCH

Our age worships small things: the microchip, recombinant genes, mechanical parts built at the molecular scale. Sometimes forgotten is a respect for what defined great engineering works of the past. The grace and grandeur of tall buildings, bridges spanning broad waters and other massive creations have been monuments to human ingenuity.

In this special report, SCIENTIFIC AMERICAN focuses on just a few of the most colossal civil engineering projects of our era. Asia, with its high-growth economies, has lately shown particular enthusiasm for record-setting projects. The huge, much discussed Three Gorges Dam across China's Yangtze River is rivaled by other gigantic constructions in Malaysia, Japan and Hong Kong. Their unmatched dimensions have tested the limits of construction technique, materials science, computer simulation and wind-tunnel testing... but not of the imagination. *—The Editors*

PHOTOGRAPHS COURTESY OF HONSHU-SHIKOKU BRIDGE AUTHORITY



The Longest Suspension Bridge

The Akashi Kaikyo Bridge has broken many records and weathered an earthquake—even while it is being completed

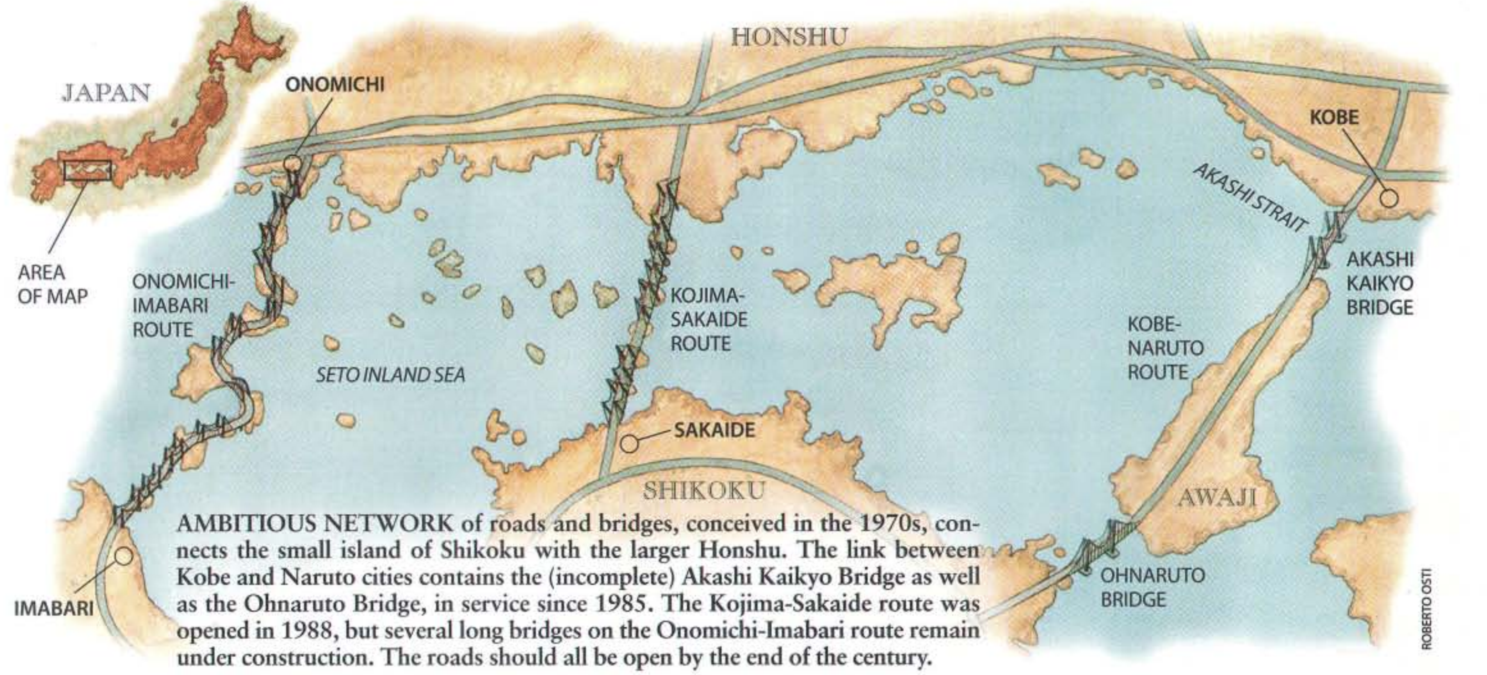
by Satoshi Kashima and Makoto Kitagawa

When it opens to traffic in April 1998, the Akashi Kaikyo Bridge will span almost four kilometers—3,910 meters, to be exact. The world's longest suspension bridge, it will help connect the island of Shikoku with the rest of Japan, while allowing free passage to ships in the international navigation channel below. Its central section will stretch 1,990 meters, its towers will soar 283 meters above the water, and its cables will carry tensile forces of 120,000 metric tons—far more than any other bridge.

The bridge will be the crowning glory of an elaborate system connecting Japan's four main islands: Honshu, Hokkaido, Kyushu and Shikoku. The smallest, Shikoku, has a population of about four million and is separated from the largest, Honshu, by the Seto Inland Sea. In the 1930s Chujiro Haraguchi, an engineer with Japan's Ministry of Interior who later became mayor of Kobe, proposed a bridge to link the two islands. He was inspired by American suspension bridges such as the Golden Gate Bridge in San Francisco, then under construction. But in those years Japan's economy and engineering skills were not up to such a feat.

In 1959 the Ministry of Construction as well as Japan National Railways began to investigate plans for bridging the two islands. The Honshu-Shikoku Bridge Authority was established in 1970 to design, construct and maintain a highway and railway system. Its engineers decided on three prongs: the Kojima-Sakaide route, which was completed in 1988; the Kobe-Naruto route, featuring the Akashi Kaikyo Bridge; and the Onomichi-Imabari route.

VITAL LINK between two Japanese islands, the Akashi Kaikyo Bridge will be the longest suspension bridge in the world. Because it spans a four-kilometer-wide international navigation channel that must never be obstructed, its construction involved some unique challenges. One problem was carrying the cable from one tower to another, solved with the help of a helicopter pulling a lighter lead wire (*inset*).



AMBITIOUS NETWORK of roads and bridges, conceived in the 1970s, connects the small island of Shikoku with the larger Honshu. The link between Kobe and Naruto cities contains the (incomplete) Akashi Kaikyo Bridge as well as the Ohnaruto Bridge, in service since 1985. The Kojima-Sakaide route was opened in 1988, but several long bridges on the Onomichi-Imabari route remain under construction. The roads should all be open by the end of the century.

ROBERTO OSTI

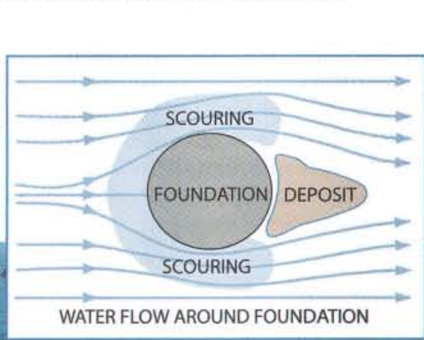
Sections of the latter two routes are now partly open to highway traffic. But along with the Akashi Kaikyo Bridge connecting Honshu to Awaji Island en route to Shikoku, several long-span bridges on the Onomichi-Imabari route are still to be completed. They should be finished within the century.

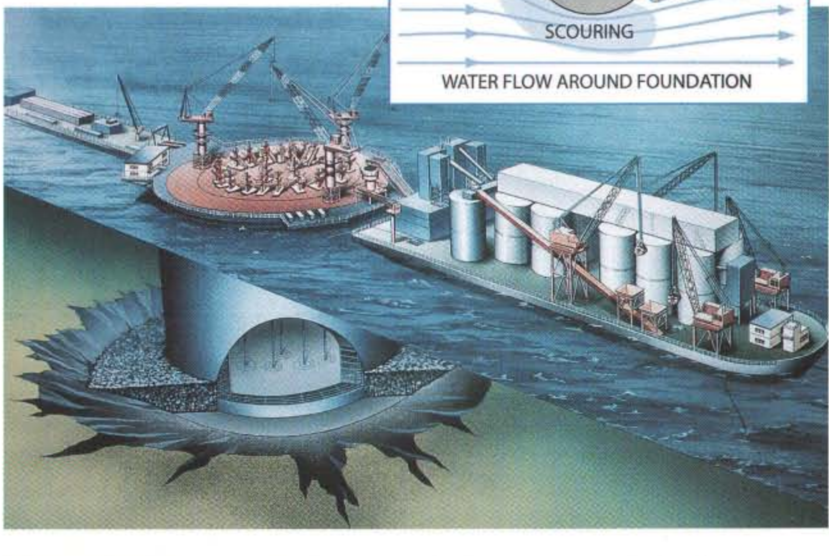
The Akashi Kaikyo Bridge is estimated to cost 500 billion yen (about $4 billion) and will carry three lanes of traffic in each direction. Along with the 400 engineers of the bridge authority, an uncounted number of engineers in the private and academic sectors contributed to its design and construction. Even apart from the mechanical stresses on the structure resulting from its sheer length, the bridge poses several challenges. The Akashi Strait ("Akashi Kaikyo"), which it crosses, must remain open to marine traffic even during construction. Engineers worried that if a ship accidentally collided with one of the towers, a major disaster could ensue. So they placed the two towers of the bridge outside the navigation channel, almost two kilometers apart. Each tower rests on the sandy gravel and soft rocks making up the seabed.

Granite, a hard rock that supports most of the world's long bridges, underlies the Awaji Island shore. But the granite bed falls rapidly away under the strait, yielding to a surface layer of hard mud and sandstone. Near the Honshu shore the seabed is lined with gravel, covered in places by soft, shifting alluvial soils. So the foundations of the Akashi Kaikyo Bridge had to be laid not on hard rock but on sedimentary rocks and semicemented gravel.

The engineers placed the two shoreline foundations of the bridge on dry, reclaimed ground. To design the tower foundations, engineers sampled the undersea strata and confirmed

STEEL CAISSONS, on which the bridge towers rest, were fabricated and towed to their respective sites (*bottom left*). The caissons, 80 meters wide and some 70 meters high, were filled with water and sunk into the excavated seabed. Later a barge mixed marine concrete and poured it continuously for three days and nights, displacing the water and fixing the caissons in place (*bottom right*). Because ocean currents threatened to scour away the gravel around the caisson (*inset*), rocks weighing a metric ton each were arranged around the base.





PHOTOGRAPH AND DRAWINGS COURTESY OF HONSHU-SHIKOKU BRIDGE AUTHORITY; LAURIE GRACE

that the ground was strong enough to support a tower weighing 25,000 metric tons without allowing it to sink or tilt. One tower was eventually placed in sandstone and the other in gravel, so that the outer spans of the bridge came to be 960 meters each, and the central span 1,990 meters.

Such a long center span makes the bridge more susceptible to being blown out by the wind. So aerodynamic engineers constructed a scale model 100 times smaller than the bridge and put it through repeated testing in a wind tunnel. The optimal design they came up with should be able to withstand winds of up to 290 kilometers per hour.

As a dredger, operated from the water's surface, excavated the seafloor and smoothed it, shipbuilding factories fabricated two cylindrical caissons, chambers used for underwater construction. The caissons are about 80 meters in diameter and 70 meters in height, the largest ever constructed. Each caisson is double walled and, despite a gross weight of more than 19,000 metric tons, buoyant. Twelve tugboats towed each caisson to its respective site, and during a few hours of slack tide and relatively slow water current, workers sank them by pouring water between the two walls. The cylinders settled on the seafloor within five centimeters of the desired location.

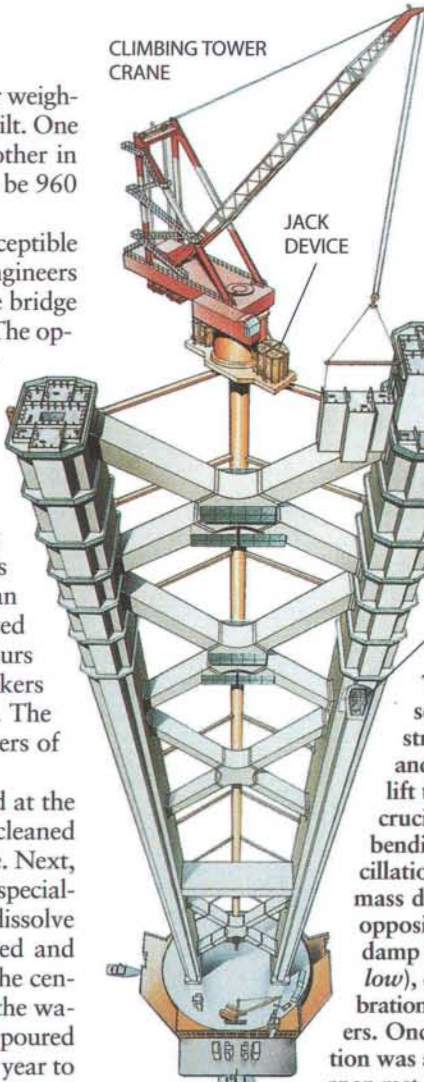
The central compartment of a caisson is not sealed at the bottom but sits directly on the seafloor. Technicians cleaned the area by sucking out soil and gravel through a pipe. Next, a stable barge at the surface mixed marine concrete, a specially developed variety that is highly fluid but does not dissolve in water. To minimize flaws, the concrete was mixed and poured continuously for three days and nights into the central chamber of the caisson. Then engineers drained the water in the outer chamber, installed reinforcing bars and poured concrete in there as well. The concrete castings took a year to finish.

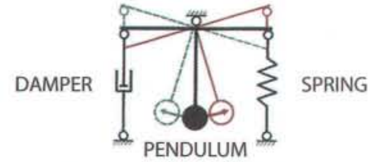
Even as the concrete was being poured, engineers were worrying about the stability of the undersea foundations. When a strong tidal current flows around a submerged structure, it forms a horseshoe eddy that scours away the soil and gravel around it. Using laboratory tests and on-site experiments, scientists had found that the scouring occurs when the current flows faster than two meters per second. After the caissons were sunk, net bags filled with gravel were laid just around it. Later, for long-term protection, workers placed rocks weighing a metric ton each over a broad area twice the radius of the caisson. At present, there is no scouring except at the edge of the protective layers.

Twin Towers

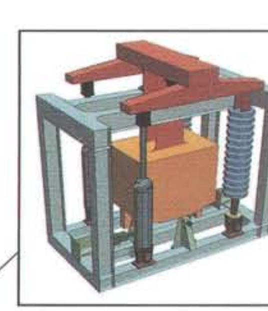
The bridge towers, 56 meters higher than those of the Golden Gate Bridge in San Francisco, are of an unprecedented scale. They are very flexible, the tops bending easily with the motion of the cable. Inside, each tower is divided into 102 floors by horizontal diaphragms, with an elevator running up the middle. Thus, a tower is comparable to a 102-floor high-rise with a floor area of 100 square meters, that of an apartment.

Wind-tunnel experiments showed that a vortex around the tower tops would make them vibrate in a direction parallel to the bridge's length. To reduce the oscillation, engineers decided on a cruciform cross section for each tower. In addition, tuned mass dampers were added within each tower shaft. Such





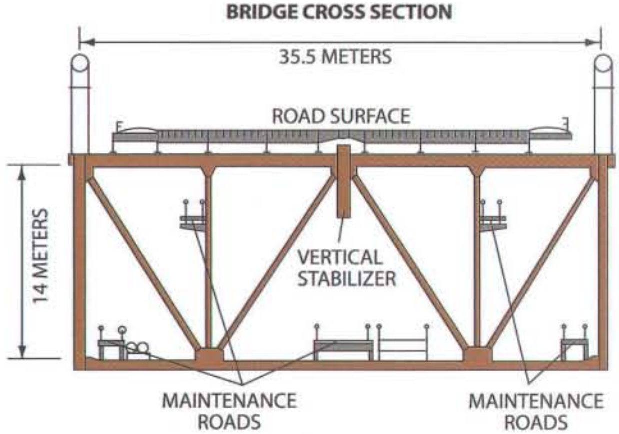
MECHANISM OF DAMPER

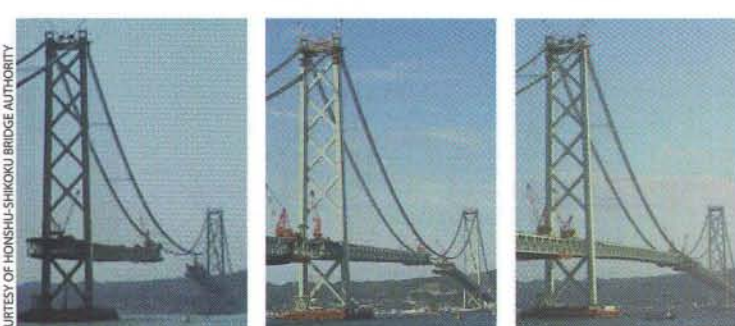

TUNED MASS DAMPER

COURTESY OF HONSHU-SHIKOKU BRIDGE AUTHORITY

TOWERS reaching 283 meters above sea level were constructed by a bootstrapping crane: it pulled up sections and placed them, then climbed on top to lift the next block (*left*). The blocks have cruciform shapes that resist twisting and bending. For further protection against oscillations, the towers incorporate tuned mass dampers, pendulums that move in the opposite direction to the tower and thus damp its motion (*above*). Truss girders (*below*), designed in a wind tunnel to resist vibrations, were attached in sections to the towers. Once a girder was secured, the next section was added, until the two ends of the main span met in August 1996 (*sequence at bottom*).

BRIDGE CROSS SECTION





COURTESY OF HONSHU-SHIKOKU BRIDGE AUTHORITY

devices, used for the first time in a bridge, contain pendulums that oscillate in a direction opposite to that of the tower, thus damping its motion.

To fabricate the towers, designers divided each into 30 blocks, the height of a block being about 10 meters. Each block was further divided into three cells, whose weight would not exceed 160 metric tons, the capacity of the crane.

The tower must be vertical to within one part in 5,000, meaning that its tip should be offset less than six centimeters from the central vertical line. To realize this accuracy, technicians temporarily assembled the fabricated blocks in a shop, then ground and polished their sectional planes to the required flatness. Afterward, they separated the blocks and transported them to the site.

A climbing crane erected the tower by a bootstrap method. After it had laid each block, the crane jacked itself up to the next level and hoisted up another one. The innovative device minimized the use of temporary scaffoldings and therefore lessened the time and cost of construction.

The next phase involved setting up the cables. Conventional wires, which have a tensile strength of 160 kilograms per square millimeter, proved too weak. From metallurgical studies, engineers devised a low-alloy steel with added silicon to reach a strength of 180 kilograms per square millimeter. As a result, they could use a single cable on each side to hold up the roadway. The simplified structure reduced the total weight and the construction period.

To set up the cable without disturbing the navigation channel, a helicopter first ferried a pilot rope across the strait. Using the pilot rope to pull up stronger ropes, workers erected a catwalk. Winches placed along the catwalk then pulled each strand tight. At midnight, when the sun's heat would not affect the metal, engineers adjusted the shapes of the strands so that each would carry equal weight.

On January 17, 1995, just after the cables had been erected, a 7.2-magnitude earthquake struck a broad area near the construction site. Its epicenter was a mere four kilometers away. The earthquake devastated the city of Kobe and damaged roads, railways and other infrastructure in the area. After surveying the region, geologists determined that a new fault had been created near the bridge, 14 kilometers deep. As a result, the foundations had shifted, expanding the central span of the bridge by 80 centimeters and the Awaji-side span by 30 centimeters.

In designing the bridge, engineers had considered the effect of an 8.5-magnitude earthquake caused by a movement of the Pacific plate as far as 150 kilometers away. In addition, they had simulated the stress on the bridge of a strong wind and an earthquake, of a level expected to occur only once in 150 years. The designers had not, however, anticipated that the foundations might shift because of a new fault below.

Only Connect

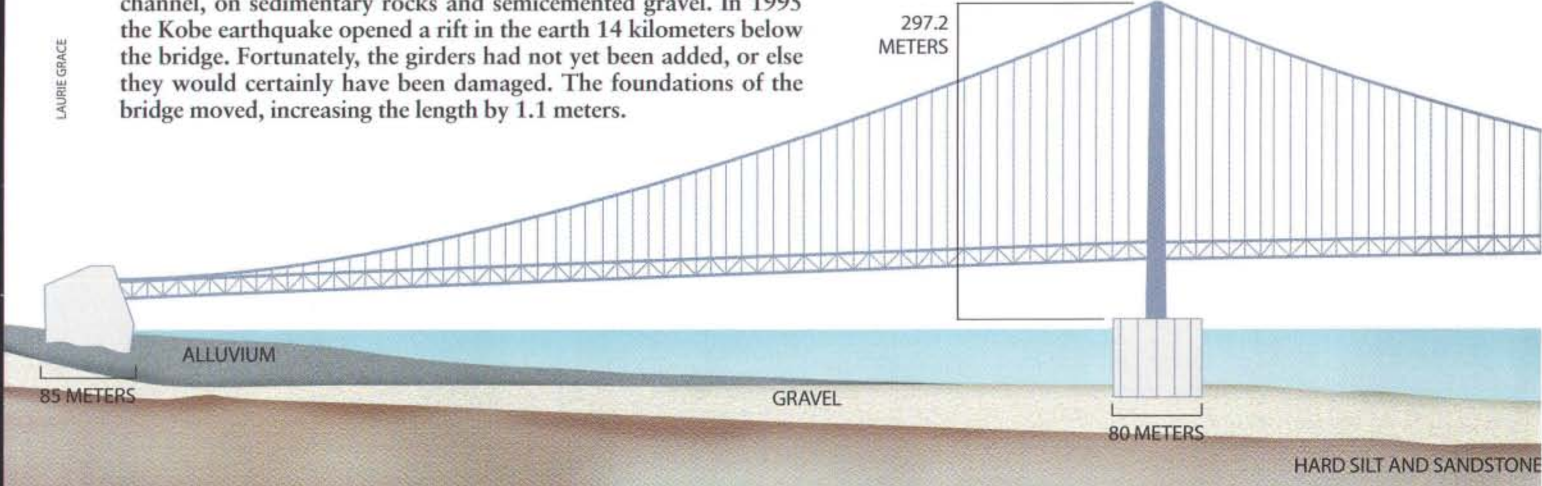
Luckily, the towers and cables suffered no damage, the cables adjusting easily to the increased length. But engineers redesigned the girders so that they would add 1.1 meters to the bridge length and, a month later, resumed construction. In hindsight, they were fortunate that the quake happened before the bridge had been finished, because some structures such as the expansion joints that were later inserted might have been damaged. The quake relieved the earth's stresses, making such mishaps less likely in the near future.

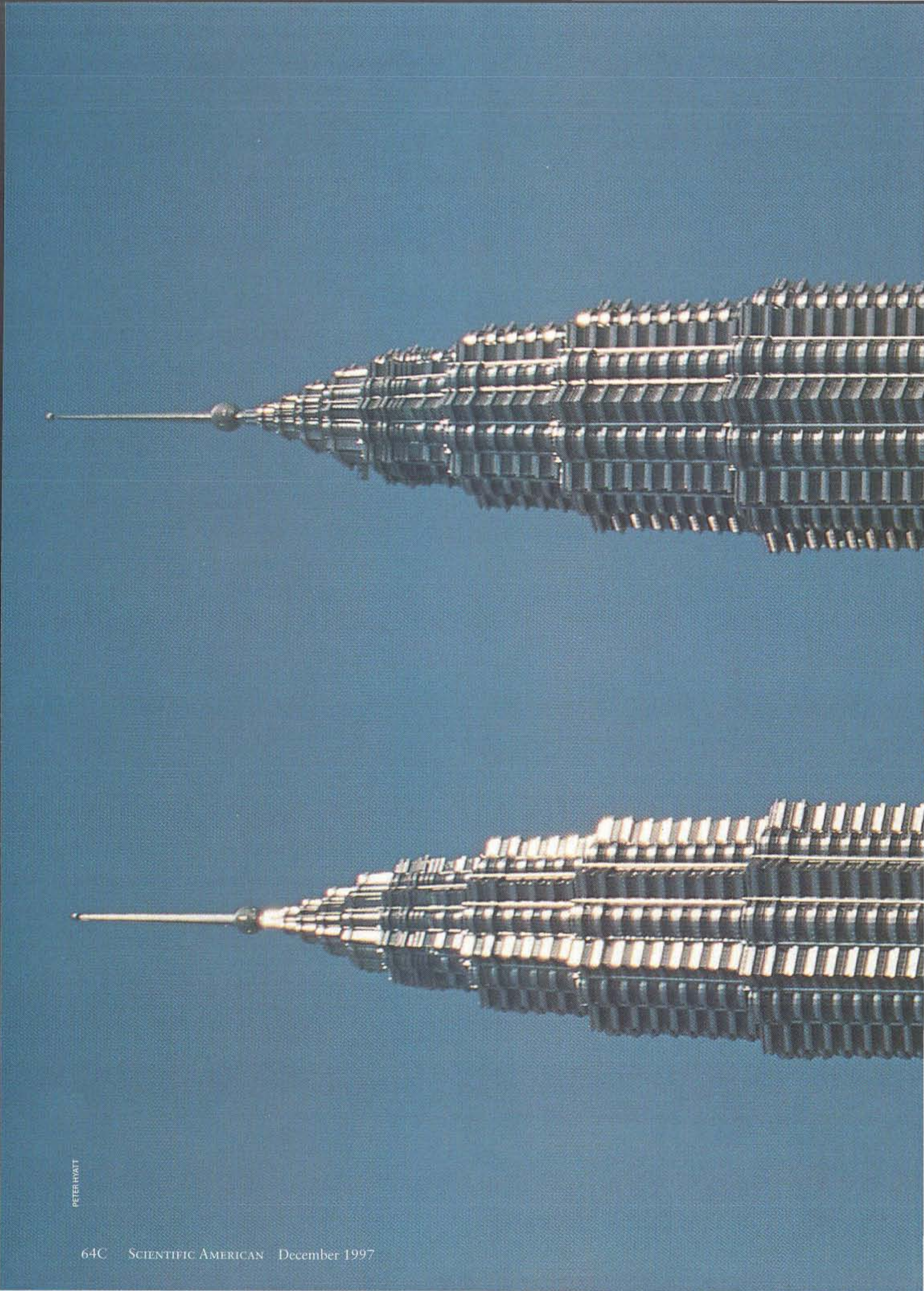
In designing the girders, engineers found that a particular twisting oscillation, excited by the wind, was liable to pose a problem. If this resonance was not damped, it could cause the bridge to fall apart. Again utilizing a wind tunnel, they designed a reinforced truss girder that did not display this resonance and installed vertical stabilizing plates under the median strip of the bridge to reduce the oscillations. Perforated gratings, laid on the central part and both sides of the deck surface, also proved to be effective.

In June 1995 workers lifted the truss girders onto the towers using a 3,500-metric-ton floating crane and installed them. Then smaller truss members, preassembled into sections of 28 meters, were carried to the front of the girders and connected to them. Thus, the two ends of the bridge stretched toward each other until, in August 1996, they met.

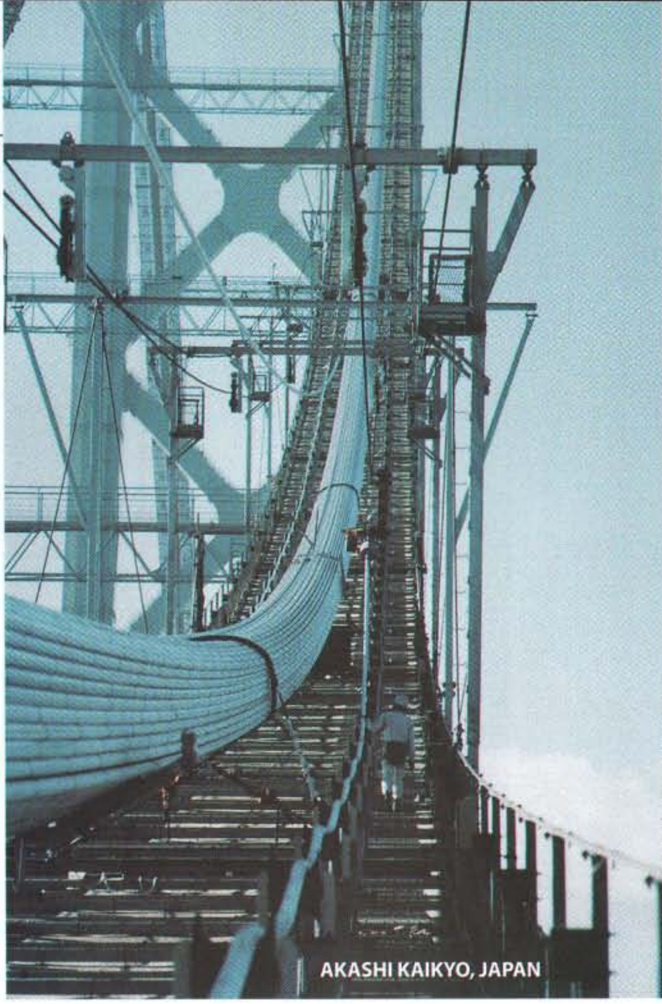
At present, workers are adding the finishing touches: placing electrical lines, paving the roadway and so on. After its opening this coming spring, the bridge should serve the people of Japan for many decades to come. SA

AKASHI KAIKYO BRIDGE could at no time block marine traffic during its construction. So its main towers were erected outside the channel, on sedimentary rocks and semicemented gravel. In 1995 the Kobe earthquake opened a rift in the earth 14 kilometers below the bridge. Fortunately, the girders had not yet been added, or else they would certainly have been damaged. The foundations of the bridge moved, increasing the length by 1.1 meters.





PETER HYATT



COURTESY OF HONSHU-SHIKOKU BRIDGE AUTHORITY

The Authors

SATOSHI KASHIMA and MAKOTO KITAGAWA contributed to the design and construction of the Akashi Kaikyo Bridge. Kashima obtained his Ph.D. in civil engineering at the University of Texas at Austin in 1973. As the general manager of the First Construction Bureau, Honshu-Shikoku Bridge Authority, he was engaged in laying the foundations of the bridge. Kitagawa obtained his M.S. degree at Tokyo University in 1969. He is the general manager of the Tarumi Construction office, also part of the bridge authority, and helped to design and erect the wind-resistant girders.

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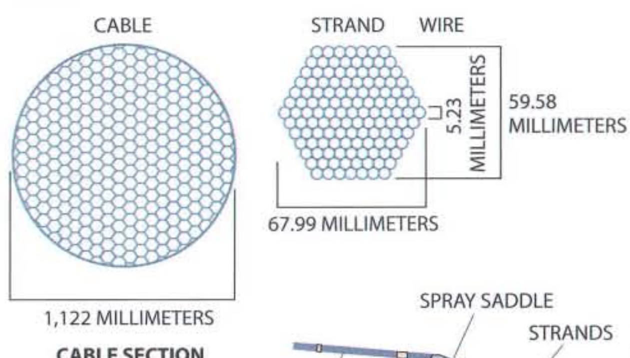
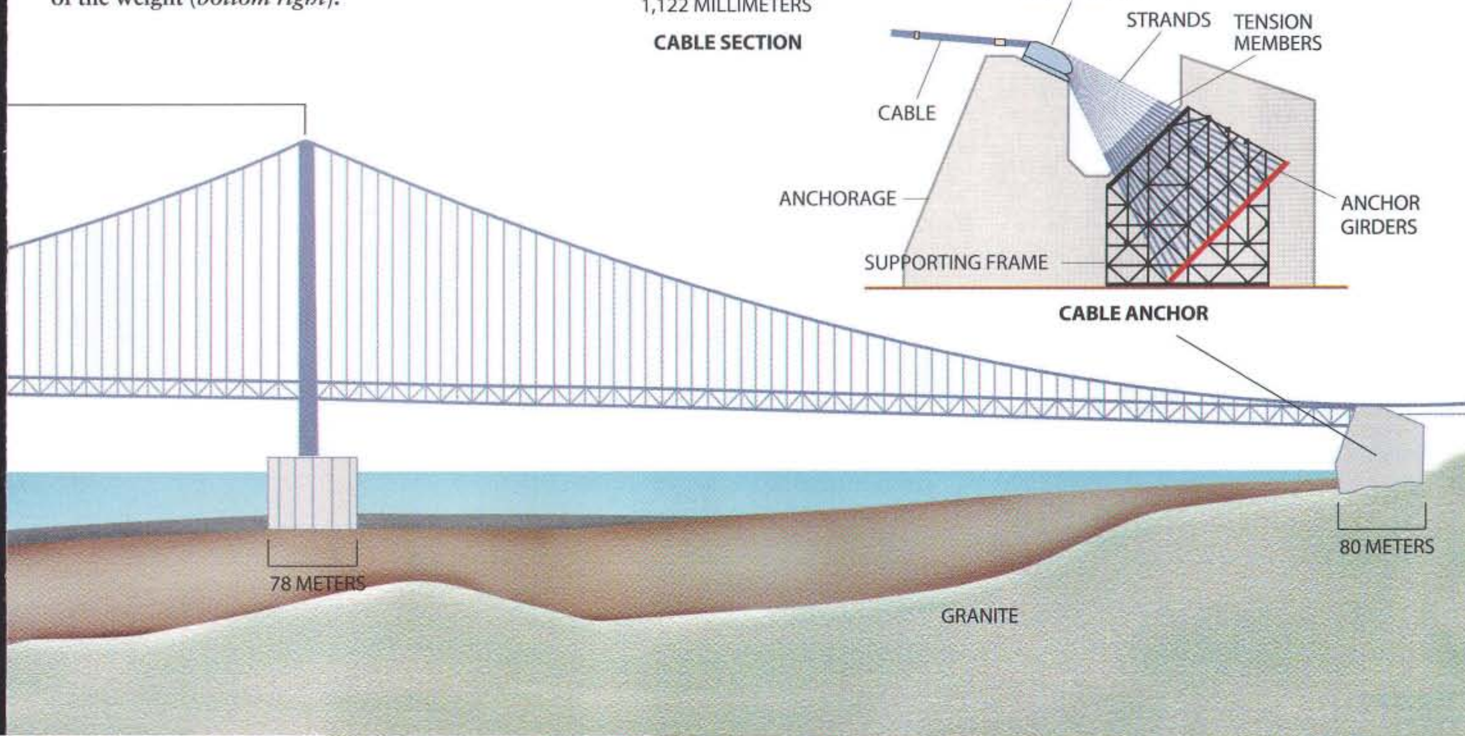
TWO CABLES, each composed of 290 strands, hold up the roadway. Each strand contains 127 high-strength wires (*top right*); the total length of the wires would encircle the earth 7.5 times. After the cables were strung across the gap between the towers, workers set up a catwalk and placed winches to pull every strand to the correct shape. The cables were fixed onto the shore foundations by an elaborate mesh designed to ensure that each strand carries an equal share of the weight (*bottom right*).

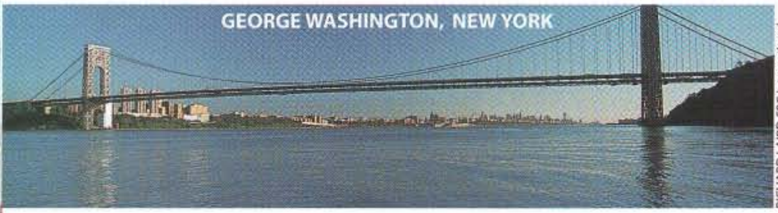




BRIDGE LENGTH AND CABLE STRENGTH

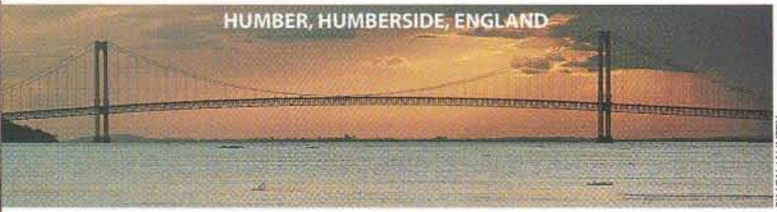
KOJI YAMASHITA *Panoramic Images*

VITO PALMISANO *Tony Stone Images*



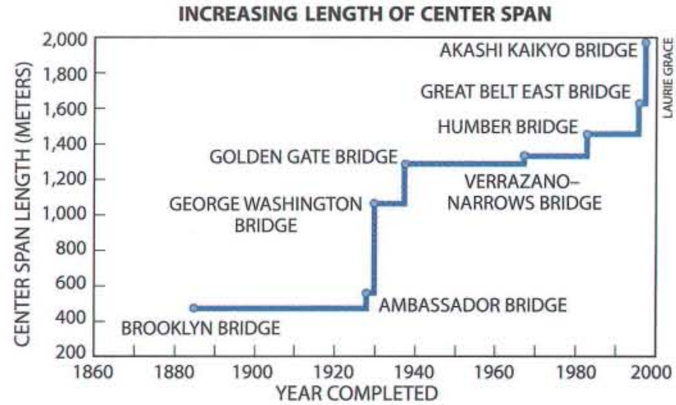
RICHARD LAIRD *FPG International*

DAVID BROWN *Panoramic Images*

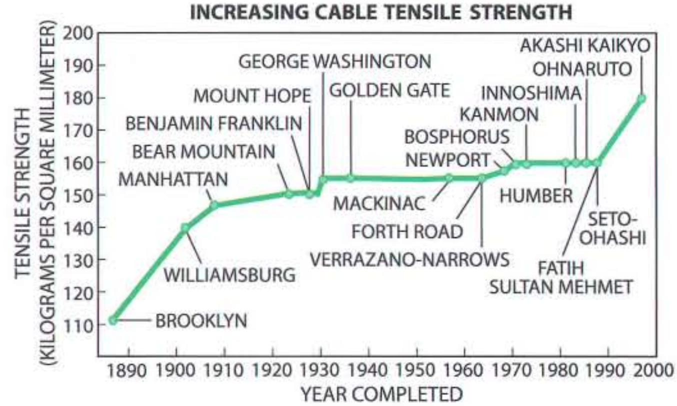


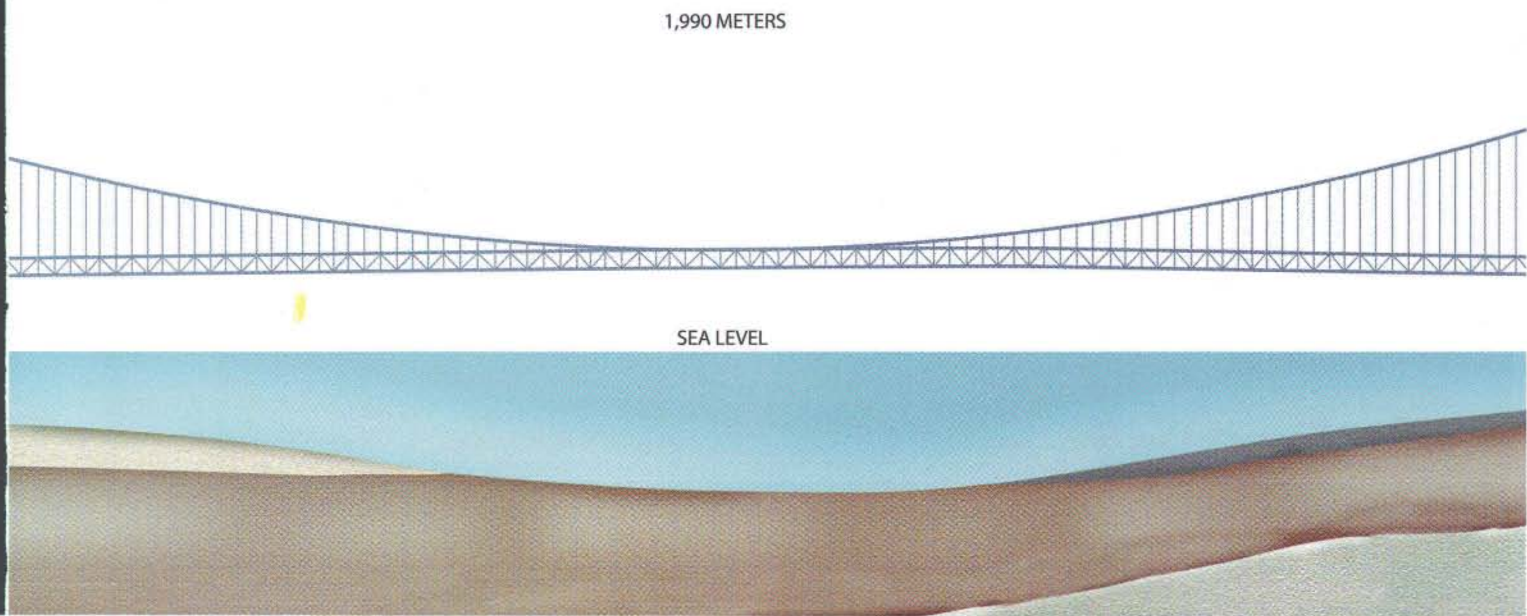
SIMON JAUNTEY *Tony Stone Worldwide*

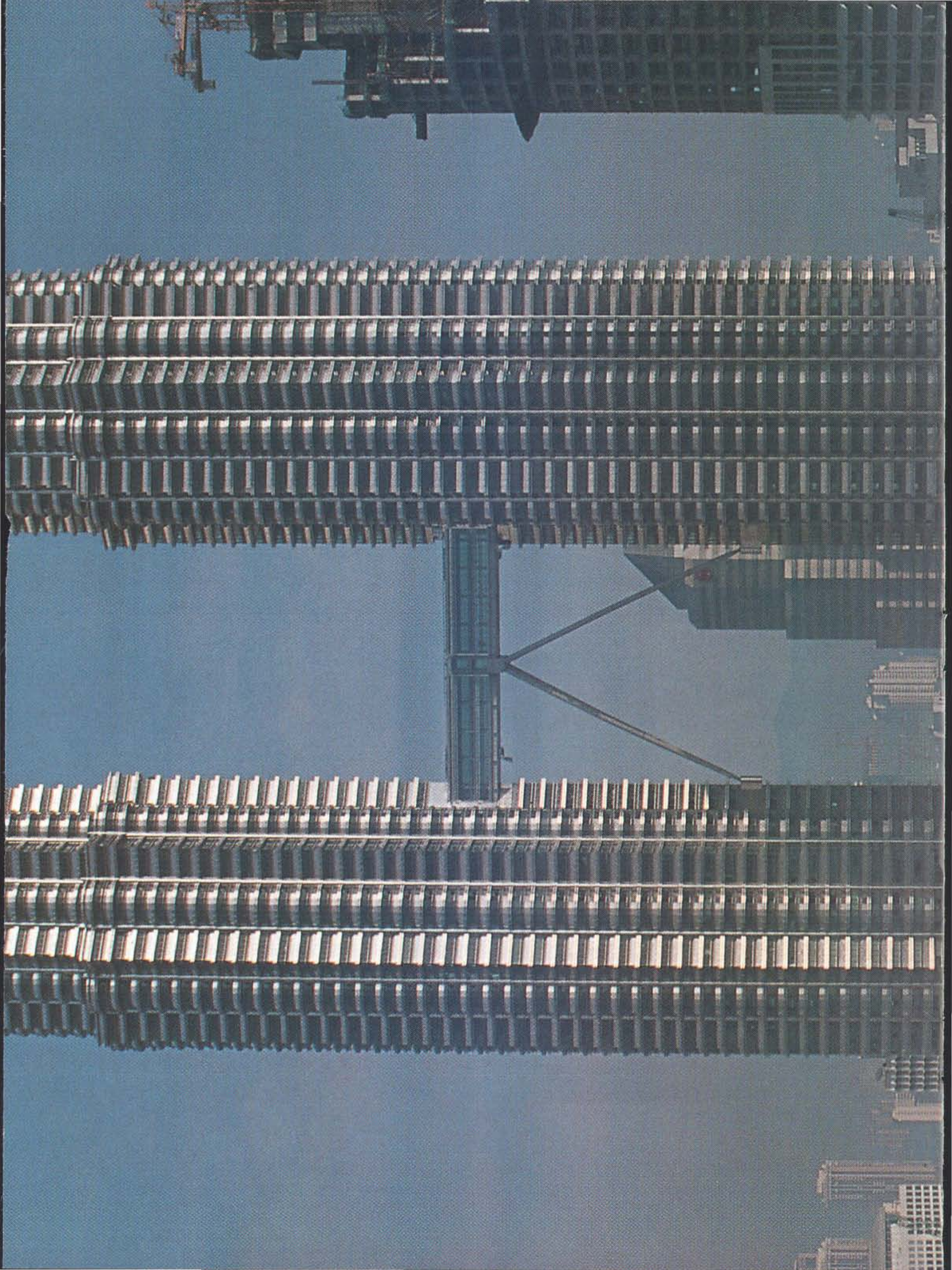
WORLD'S SUSPENSION BRIDGES have steadily lengthened since the first—the Brooklyn Bridge—was completed in 1885 (*photographs, top to bottom*). The main challenge for engineers is holding up the enormous weight of the central span. The tensile strength of the wires in the cables has increased in step with the length and the weight of the span (*charts*). Although the Akashi Kaikyo Bridge will remain the longest for a while to come, the Messina Bridge, with a center span of 3.3 kilometers, is planned for the year 2006. It would connect Sicily with mainland Italy.



LAURIE GRACE







The World's Tallest Buildings

Malaysia's Petronas Twin Towers serve as both a cultural and an economic symbol

by Cesar Pelli, Charles Thornton and Leonard Joseph

The urge to build as high as possible appears to be a common trait of human culture. From the Great Pyramid of Cheops to the Tower of Babel, many civilizations tried to craft structures that stood above their surroundings. Mesopotamian ziggurats, Chinese pagodas and Moslem minarets became symbols of religious belief, towers that reached toward heaven.

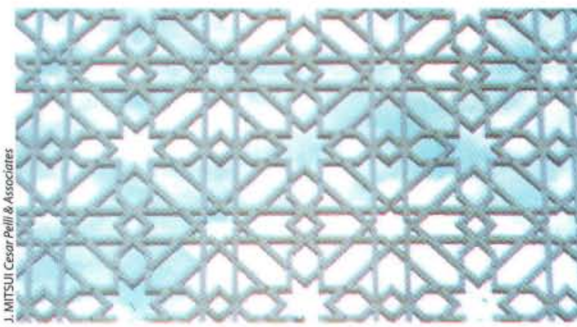
Today the modern obelisk is the skyscraper. For more than a century, architects and civil engineers have applied practical and theoretical knowledge about vertical construction techniques to transform the look of cities. Early skyscrapers borrowed ideas from the shape of Greek columns and Renaissance towers. The modernist movement that predominated after World War II avoided symbolic qualities: these flat-roofed, rectangular structures were even called high-rises, not skyscrapers. In recent years, architects have again revived interest in the tall building as cultural emblem. Preeminent examples of the trend are the world's tallest buildings, the Petronas Twin Towers, which soar above Malaysia's capital city of Kuala Lumpur.

The pinnacles of the 88-story structures reach 451.9 meters. The edifices, connected by a skybridge at the 41st and 42nd floors of both buildings, are more than simply an office complex. These recently completed buildings stand as a symbol of Malaysia's economic growth, while emphasizing the distinctly Islamic traditions of this southeast Asian nation of 19 million people.

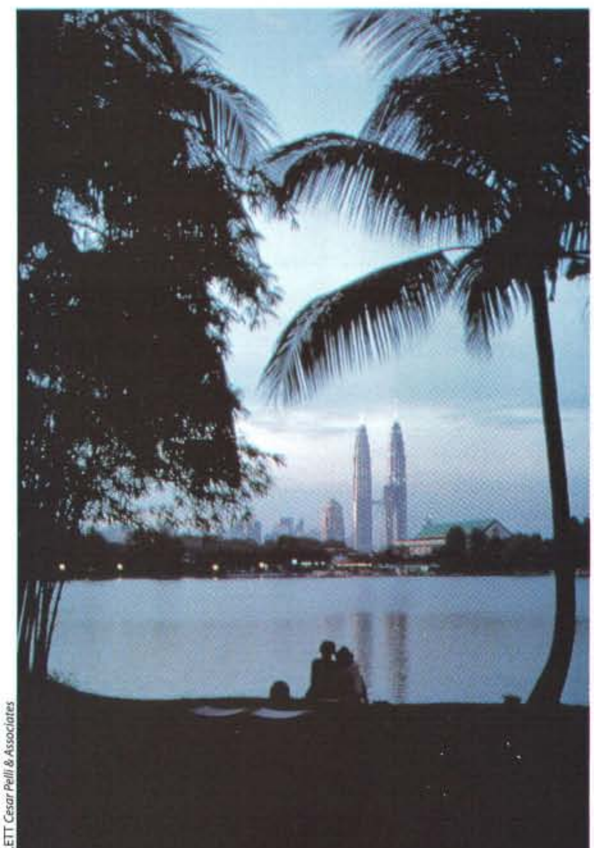
Each floor plan is a star shape with alternating round and square-cornered points, after a design drawn from Islamic art. Faceted outside walls repeat the same pattern. The project is a centerpiece of what Mahathir Mohamad, the prime minister of Malaysia, calls Wawasan ("Vision") 2020, a blueprint for the country's development, which also includes a variety of other large infrastructure projects.

Each of the tower buildings contains 213,750 square meters of floor space (equivalent to 48 football fields). Besides offices, the space is used for a petroleum exhibit center, an art gallery and state-of-the-art multimedia conference rooms. The two buildings themselves are part of a much larger complex, Kuala Lumpur City Centre Phase I, and are constructed on one corner of the former site of a racetrack, the Selangor Turf Club. The complex also encompasses a 140,000-square-meter retail and entertainment facility; a 2,600-square-meter, 850-seat concert hall; 251,000 square meters of below-grade parking for 5,000 cars; and two smaller office towers with approximately 186,000 square meters of space.

The owner of the development complex is Kuala Lumpur City Centre Holdings Sendirian Berhad, a partnership that includes Petronas, the national petroleum company, which is also a key tenant. The project developer is Kuala Lumpur City Centre Berhad. What follows is an account of the architectural and engineering decision process that began with a design competition in 1991 and moved through to the completion of the towers' pinnacles.



J. MITSUI Cesar Pelli & Associates



P. FOLLETT Cesar Pelli & Associates

ISLAMIC MOTIFS influenced the architectural design of the Petronas Towers, seen in the bottom photograph from a nearby lake.

ARCHITECTURAL DESIGN

Gateway for Malaysia

The architectural design of the Petronas Towers began, as most large-scale projects do today, with an international competition. Eight firms from Asia, Europe and the U.S. responded to the invitation from the owner and developer. All architects worked from a relatively short brief that described the project requirements—a general design for a shopping center and public spaces—and a more detailed prospectus for two towers to be occupied by Petronas in the northeast corner of the 40-hectare complex.

The towers, according to the brief, would define a gateway into this new city center. They would create "a place that people can identify as unique to Kuala Lumpur and Malaysia." It was never specified that the towers should become the tallest buildings in the world, just that they be beautiful.

The competition lasted only a short time during the summer of 1991. Within three weeks, each design firm had to prepare drawings, models and rendered perspectives to send to Kuala Lumpur. The developer's technical staff spent two weeks reviewing the proposals. Then, in August, each competitor had to make multiple presentations of its designs to audiences that included the developer and Prime Minister Mahathir. These sessions addressed technical and economic concerns as well as aesthetic and philosophical questions.

Later that month Cesar Pelli & Associates, the New Haven–based architectural firm, received notice that it had been chosen to design the first phase of the Kuala Lumpur City Centre project, which included the Petronas Towers. One never knows with certainty why one design proposal is selected. In this case, the client indicated that, as architects, Cesar Pelli & Associates had answered all the practical concerns and, most important, that the proposal met the desire for a uniquely Malaysian design.

Following the decision, a team was assembled that included Thornton-Tomasetti, structural engineers; Flack & Kurtz, mechanical engineers; Adamson Associates, production architects; Balmori Associates, landscape designers, among others.

In total, 16 firms collaborated in the design effort. This number is not unusual for a project of this size, given that the taller the building the greater the design demands of function, structure, efficiency and economy. The large complement also responded to a requirement that Western firms experienced in design and construction practices for very tall buildings should work closely with Malaysian professionals to share their technological expertise.

ENGINEERING DESIGN

Islands in the Sky

The basic engineering principles for tall building design look deceptively simple. Floor slabs and beams span from one column to another, creating open space that can then be partitioned into defined work areas. Columns carry the building load all the way down to the foundation. Parts of the structural systems must also provide lateral stiffness for stability. A shear wall, for instance, can rise through multiple floors to brace against wind and other dynamic forces, such as earthquakes.

Demands on the structure, however, increase rapidly with height. In a 40-story building, an average column carries a load equivalent to 23 floors. At 80 stories, a column in the lower 40 stories absorbs an average load equivalent to 80 floors. Doubling the height more than triples the load because of the compounding effects of the building's own weight.

As height increases, the area exposed to wind forces—a critical variable in tall building design—also expands. The lateral deflection of upper floors must be controlled. Doubling a building's height multiplies wind sway 16-fold unless the structure's stiffness is increased dramatically.

Providing upper floors with air, water, electricity, communications lines and sanitation takes up precious interior space, and the room needed for these services can grow disproportionately. Large pumps are needed in the basement to push water to the top. The bottom sections of water and air-conditioning pipes experience great pressure. Some relief from this pressure buildup comes from water storage tanks and heat exchangers dispersed throughout the building.

Firefighting and evacuation cannot be performed above 30 meters (100 feet) from ladder trucks on a street. Sprinklers, alarms, smoke-control systems and fire refuges (areas with a separate air supply) consequently become vital. Ground-based construction methods are unsuited for tall buildings: cranes, working platforms and forms (steel boxes into which concrete is poured) must climb with the building as construction proceeds. The time needed to lift workers, concrete, steel and glass can affect the project schedule. The contractors must, in effect, plan the project as if working on an island in the sky.

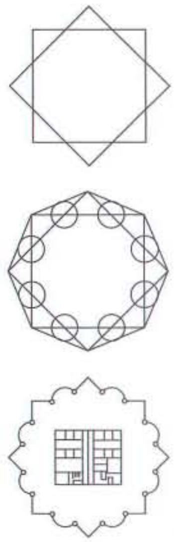
Despite impediments, buildings continue to grow taller and have yet to approach practical height limits. High-strength concrete can form compact structural members, thereby reducing constraints on building design imposed by column size and weight. Stronger steels now under development might also be used where weight limitations are critical. Wider bases are needed to provide stability against wind. Many new towers, in fact, are megastructures covering several blocks.

The main limit on height is human physiology, not structural constraints. Pressure changes and travel times in ever higher elevator runs impose a "vertical commuting" cost on occupants. The financial burden involved in building tall also sets a practical limit. These barriers, nonetheless, keep moving slowly upward.

PETER HYATT

ARCHITECTURAL DESIGN

A Multifaceted Star



Linking the Petronas Towers to Kuala Lumpur and Malaysia required rethinking the character of the traditional skyscraper to unburden it of American or European connotations. The buildings were connected to their place in several ways. The shape of the towers has its origin in Islamic tradition, in which geometric patterns assume greater symbolic importance than in Western culture.

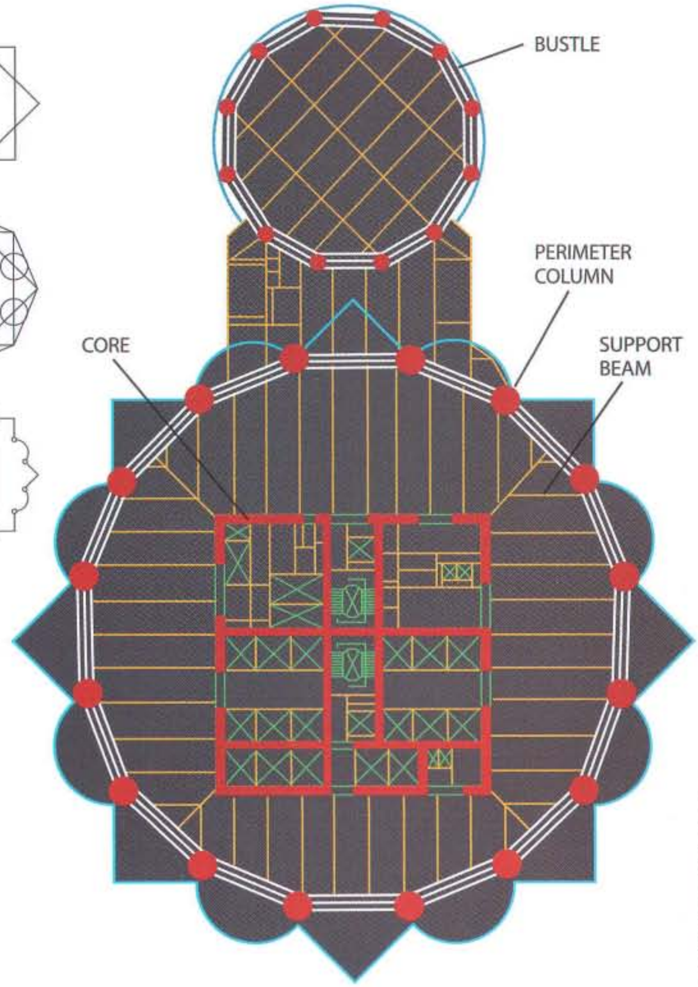
In the competition, Cesar Pelli & Associates proposed a 12-pointed star as the shape of the building perimeter, giving the building both a graceful form and very usable floor space. Prime Minister Mahathir suggested that other patterns might prove more representative of Islamic design. After being awarded the contract, we researched traditional motifs and concluded that the most common design is an eight-pointed star—achieved by superimposing two rotated squares. Further confirmation came from a drawing suggested by Mahathir, who proposed two interlocked squares. But an eight-pointed star results in an unsuitable floor plan; the exterior wall comes too close to the building core, reducing flexibility in the use of the floor space.

The architects studied many variations and proposed a form with eight semicircles superimposed in the inner angles of the eight-pointed star, creating a 16-branched form. A structural column occupies each of the 16 inner angles of the building, producing floor space that is otherwise free of columns.

Almost at the same time, development work began on the core, the hollow square of walls at the building's center that provides much of the structural support. The core, which also contains elevators, stairs, mechanical shafts, fan rooms and toilets, is the key to a well-functioning tall building. Its design must work with anticipated users' needs and floor layouts. The goal was to meet these demands with high "efficiency"—a measure that describes the ratio of usable-to-gross floor areas. The average efficiency of a typical office floor in the Petronas Towers is between 76 and 77 percent, a good ratio for a very tall building.

Achieving a compact core required a series of careful decisions. To provide efficient elevator service, each shaft accommodates multiple cabs. The number of express shafts that bring passengers to upper floors is reduced by a shuttle/skylobby system, similar to the one in the World Trade Center in New York City. Visitors to the upper half of the buildings transfer at midheight to two "local" shafts that are stacked one on top of the other. Capacity at peak hours is further increased by double-decker elevator cabs, as used in the Citicorp building in New York City and the Bank of Montreal building in Toronto.

Detailed design of the exterior wall and the public spaces started a few months later. Drawings and study models tested every element in the building. For example, the choice of glass for the windows and the design of the sunscreen—steel pipes that act as shields from the tropical sun—affect the building's overall appearance, the type of office lighting, the mechanical cooling equipment requirements and, ultimately, annual operating costs. Tentative solutions for these and other design features had to be resolved with local consultants and submitted to the client for approval.



THORNTON-TOMASETTI ENGINEERS

STAR SHAPE characterizes the floor plan of the Petronas Towers. The original concept for the plan consisted of two superimposed squares (*top left detail*), creating an eight-pointed star. It was modified—placing eight semicircles in the inner angles of the star points (*middle detail*)—to create more usable floor space. The final design contained 16 protrusions: eight points and eight lobes (*bottom detail*). The core, which consists of a hollow square of walls containing elevators, mechanical shafts and other services (*above*), connects to support beams that extend out to perimeter columns. A smaller building, or bustle, shown as a top appendage in the plan, reaches the tower's 44th floor.

H. YOUNG *Cesar Pelli & Associates*

ENGINEERING DESIGN

Building on Kenny Hill Soil

Kuala Lumpur is ringed by low mountains, but within the city only a small hill interrupts the level terrain. The site, on a space occupied by the former Turf Club, is a flat greensward. But the geotechnical and structural engineer of record, Ranhill Bersekutu Sendirian Berhad, knew from experience that the bedrock below could be very irregular.

Exposed to millions of years of weathering, limestone bedrock in this region contains caverns, spires, ravines and steep-shouldered mountains that, if above grade, would resemble a landscape from classic Chinese art. Sediment from erosion filled the valleys. These lower strata had metamorphosed to weak rock that weathered back into a type of stiff soil found in Malaysia called Kenny Hill.

The 300,000-metric-ton weight of each tower could be spread over a large concrete slab called a mat. But each tower would exert 1,140 kilopascals of pressure, more than twice the weight-bearing capacity of Kenny Hill soil and enough to cause the foundation to fail. To avoid such a possibility, the initial concept for the foundation used massive concrete-filled piers, two holes filled with concrete under each column. And more piers would also sit underneath core walls. The piers would pass through the soil before bearing down on bedrock.

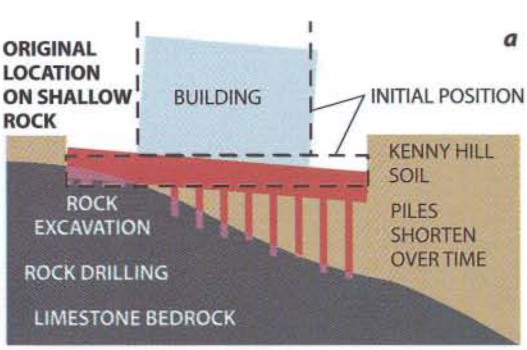
As results by soil probes came in, the design team faced a quandary: bedrock under both towers started shallow, 15 meters down, but sloped steeply to deeper than 180 meters. Excavation to a depth of 21 meters was needed for the basement, which would penetrate into rock at one end. At the other end, more digging would sink piers down through the soil until they reached bedrock. Pier installation at the deep end would be risky, slow and costly, exceeding normal construction practices. And the piers' inevitable shortening could be different for each foundation support, producing unacceptable tower tilting. (Pier length diminishes from the extra loads imposed by adding upper floors and the weight bearing down as tenants move into the buildings.) Any shortening could be evened out, but the process would require extra digging and other measures that would increase cost.

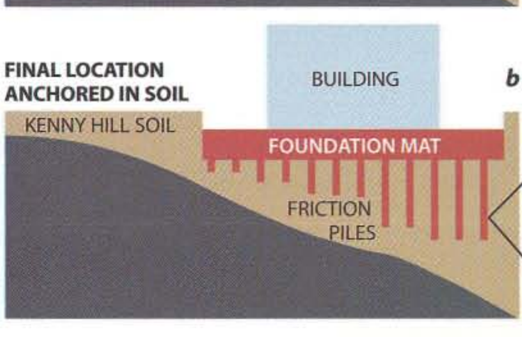
Fortunately, the site was large enough for the design team on the project to consider moving the foundations. Shifting both towers 60 meters southeast put at least 55 meters of soil below each tower basement. Instead of resting on bedrock, they would anchor within the soil. The new location provided more room between the towers and nearby streets, which improved traffic flow and left room for off-street drop-off lanes and parking entry ramps.

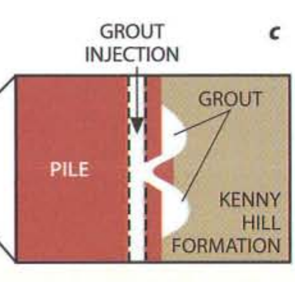
At the new site, the towers were to sit over opposite banks of a filled ravine, with bedrock 80 to more than 180 meters below. The plan called for an entirely different foundation system. A concrete mat would spread building weight to drilled 1.3-meter-diameter piles, structures narrower than piers. These piles would transfer the weight of the tower to the soil more gradually than a mat alone would. Friction between the surface of a pile and surrounding soil would prevent the foundation supports from sinking, much as a nail stays firmly rooted in wood. Settlement would then occur in the zone of soil between the pile tips and bedrock. Varying the pile lengths so that all the supports remained at about the same distance above the sloping rock would result in even settlement, avoiding tilt of the foundation.

The use of this type of support brought a new concern. The solidity of Kenny Hill soil depends on interlocking grains of sediment, whose sand and silt had once been rock. The soil in an excavation bed normally swells as digging proceeds and the weight of the soil above is removed. The interlocking grains of soil would decouple as the soil expanded. To avoid reducing soil solidity, we decided to sink the piles from near ground level. The piles then would act as "soil nails" to restrain the excavation against swelling.

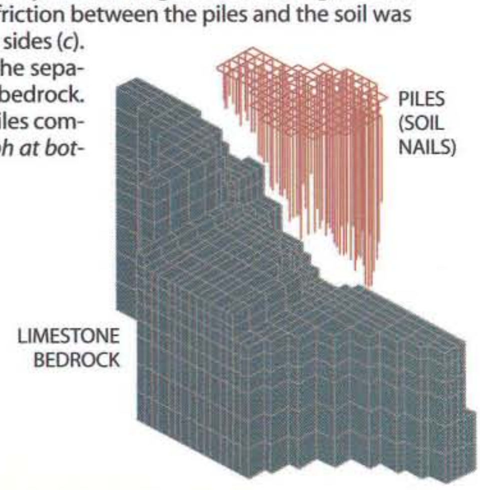
Each final foundation consisted of 104 barrettes (rectangular cast-in-place piles up to 1.2 by 2.8 meters) dug as deep as 125 meters. Barrette construction proceeded with crews lowering a cage of steel reinforcing bars into each hole, which was then filled with concrete. Friction between the piles and the soil was enhanced by injecting grout—a sand-and-cement mixture that was pumped down embedded pipes and out the side of the piles. Once hardened, the bumps of grout on the outer surface of the barrette increased soil friction. Finally, each foundation was completed by casting a concrete mat atop the barrettes. Each 4.5-meter-thick mat required 13,200 cubic meters of concrete. Casting each mat took place in a short, intense burst of activity: a concrete truck arrived to deliver its contents continuously every 90 seconds for two days.







SOIL NAILS, or friction piles, keep the foundation from sinking. If piles driven into the bedrock had settled differently, the building would have begun to tilt (*a*). Instead, at a new location (*b*), friction between the piles and the soil was enhanced by forcing grout out the sides (*c*). A computer model (*right*) shows the separation between the piles and the bedrock. Casting a concrete mat atop the piles completed the foundation (*photograph at bottom on opposite page*).



THORNTON-TOMASETTI ENGINEERS

ENGINEERING DESIGN

Concrete Monoliths

The earliest tall buildings had to be made of stone, brick or conventional concrete, which creates unacceptably large and heavy walls and columns. Steel overcame this limitation at the beginning of the skyscraper era. But advances in concrete technology have again made concrete attractive. Adding microsilica and other compounds to basic concrete can greatly increase its strength. (Microsilica is a superfine dust that is a by-product of electronics manufacturing.) This high-strength concrete can be used to form more compact structural elements. Other materials also give concrete superior properties. Superplasticizing agents make it easy to pump. When water reacts chemically with cement particles and other components to form concrete, heat is released. Excessive heat can crack the concrete. Partially replacing cement with fly ash from coal power plants avoids the problem.

Concrete is ideal for the columns and core walls of the Petronas Towers because of its familiarity to local contractors. It can be lifted into place using buckets or pumps rather than massive cranes, and it is easy to mold into complex shapes. Concrete also helps to damp the natural tendency of any tall structure to move back and forth slightly in the wind; its ability to attenuate vibrations is twice that of steel. These back-and-forth oscillations—one cycle of which occurs every nine seconds in the towers—are slower because of the concrete's mass. Both characteristics reduce the building's response to wind to a comfortable level.

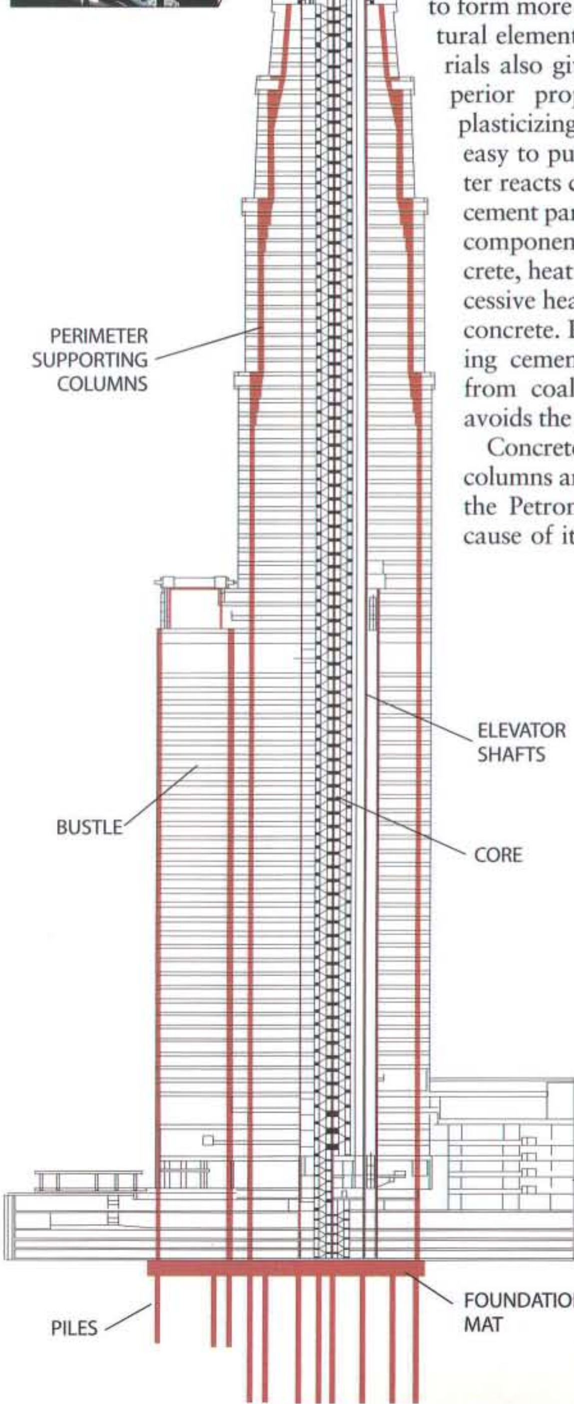
Lateral strength and stiffness is essential to tall buildings. Shorter structures use the central core alone as their spine, but the compact core of the Petronas Towers would have only half the strength and stiffness needed to resist deflection from wind and other forces. The necessary strength comes from a combination of the core walls and a frame of concrete beams and columns along the perimeter as well as outriggers (stiff beams reaching from the core to the perimeter). Steel-framed cantilevers reach beyond the perimeter columns to form star-like protrusions, which offer the added advantage of giving tenants unobstructed views.

The facade uses one-story-tall modular panels, each four meters tall by 1.4 meters wide, with interlocking tongue-and-groove joints for rapid installation. Stainless-steel and tinted glass panels with self-cleaning teardrop sunshades adapt well to the tropical setting and provide a lightweight enclosure with strong visual texture.

Several aspects of the towers' design reduce wind effects. Tapering toward the top diminishes the area exposed to faster, higher-altitude winds. The columns on upper floors are set back (shifted closer to the core) by sloping them inward. Wind drag on the towers' ribbed, rounded shape is less than for a rectangular tower, though more than for a smooth cylinder. The ribbing on the buildings' exterior also creates small areas of turbulence that break up larger vortices of air that could add to the buildings' swaying. It was discovered in wind-tunnel studies that air blowing through the gap between the structures does increase building movement, but not by very much.

Luckily, Kuala Lumpur also has a benign climate for tall buildings. It is not an area marked by seismic activity. And, close to the equator, it is not subject to hurricanes and typhoons. Tropical thunderstorms bring heavy rain and lightning strikes but not exceptional winds.

For high buildings, the time needed to build one floor dictates the schedule. Contractors sped up the schedule by implementing several strategies. For building core walls, jacks raised work platforms and forms (steel boxes for pouring concrete columns) as complete assemblies. The steps in building concrete-framed floors—forming, lathing (setting reinforcing bars), casting, finishing and curing—take longer than for building columns and so would have slowed the work pace. To avoid this bottleneck, construction crews fastened steel beams to the core and columns, placed a metal deck on them, then poured a much thinner layer of concrete. This process eliminated many of the steps required for an all-concrete floor.



EIGHTY-EIGHT STORIES terminate in a 63.2-meter-tall mast (*left*). Columns on upper floors are set back, allowing tapering at the building's top that reduces the area exposed to high-altitude winds (*top photograph*). The observer dwarfed by the mast's ring ball gives a sense of the building's scale (*bottom photograph*).

THORNTON-TOMASETTI ENGINEERS (*top photograph*); CESAR PELLI & ASSOCIATES (*bottom photograph*); CESAR PELLI & ASSOCIATES (*drawing*)

ARCHITECTURAL DESIGN

Highlighting the Void

J. PICKARD *Cesar Pelli & Associates*

Perhaps the most important architectural decision was to design the towers as skyscrapers with distinctive silhouettes. Cesar Pelli & Associates also took the unusual step of making the pair a symmetrical composition. In the modern movement, architects typically attempt to couple skyscrapers in asymmetrical arrangements. They usually do so by making the two structures of different heights. If equally tall, they are set diagonal to each other—the World Trade Center being a notable example. Like sculpture, the modernist building becomes a free object set in indeterminate space. As such, it avoids symbolic expression.

In the final design, which breaks from the modernist tradition, the towers are symmetrical. Their arrangement creates a distinctive space between them, adding to the symmetry. The separation constitutes the key element in the composition. Each tower has its own vertical axis, but the axis of the total composition is the intervening space. Through Frank Lloyd Wright, many architects have been influenced by Lao-tzu's teaching that the reality of a hollow object is in the void and not the walls that define it.

The space between the towers can be perceived as the most real element in the total composition. The visual power of the emptiness was enhanced by adding a midlevel skybridge not specified in the original client brief. The bridge and its supporting structure create a 170-meter-high portal to the sky, an element that can be seen as a door to the infinite. The Petronas Towers are thus unlike any Western skyscraper. This quality of the buildings is not derived from Malaysian tradition. But because it appears for the first time in Kuala Lumpur, it will be forever identified with its place. The Eiffel Tower is synonymous with Paris, for instance, although its structure and form were not derived from Parisian or French architecture.

ENGINEERING DESIGN

Bridging the Sky

THORNTON-TOMASETTI ENGINEERS

THREE DAYS were needed to lift the 325-metric-ton skybridge after lightning damaged control equipment.

The skybridge is an essential functional component of the Petronas Towers. Linking two skylobby levels in both towers permits easy access to meeting rooms, a *surau* (prayer room), an executive dining room and other offices. The skybridge is fire-resistant, so its midheight location provides an emergency exit from one tower to the other. This reduces the demand on other fire routes elsewhere in the building.

After various options were studied, an arched bridge supported from below was chosen. Other possible designs considered included a structure suspended from a cat's-cradle-like support and one held by cables above the bridge. The chosen arch configuration permits the use of thin walkway girders instead of trusses with crisscrossed members.

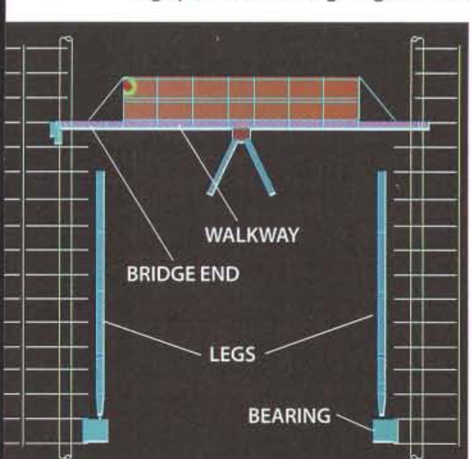
Bridge props made of 1.1-meter-diameter steel pipes rise diagonally from low supports on each tower, meeting at the middle of the bridge. The locations of the supports minimize rising or sagging of the bridge floor as the towers move. Wind-tunnel tests of a bridge model showed that the wind-induced vibrations of these flexible legs could cause fatigue cracking at some welded joints, so they were fitted with damping devices that reduce movement.

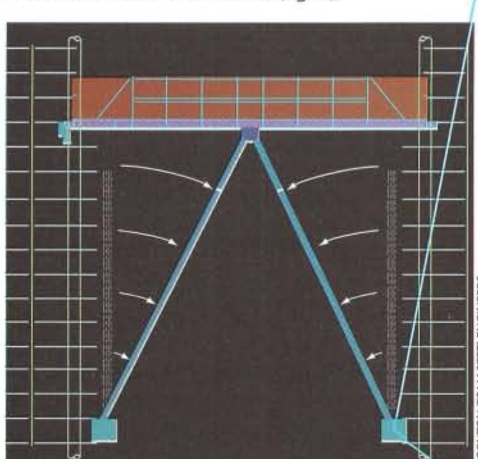
Bridge erection presented a special challenge. The structure was fabricated in South Korea and transported in pieces to Malaysia. The contractor who erected the bridge assembled most of the structure on the ground. Jacks then lifted the legs and the bridge ends. The biggest challenge was lifting the 325-metric-ton middle section, which comprised three quarters of the walkway length. Jacks that pulled eight high-strength cables could have lifted the structure in 20 hours, but the operation stretched to three days when lightning strikes twice burned out control equipment.

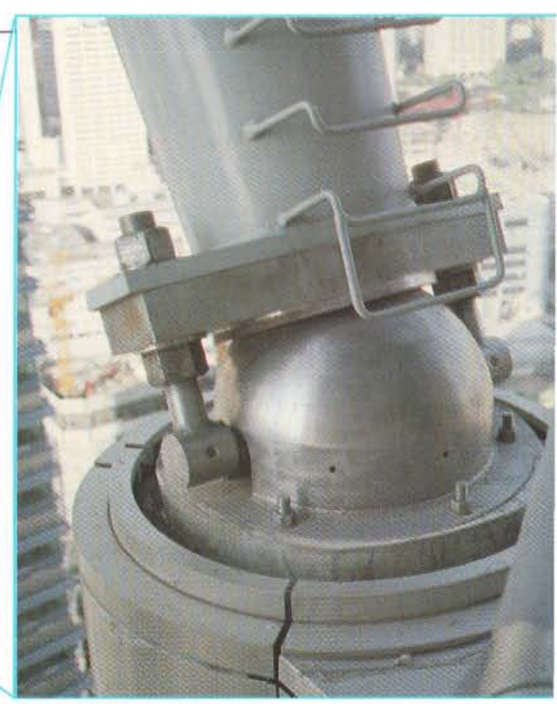
The pinnacles presented another hurdle. Considering the great height of and difficult access to the pinnacles, the client requested a low-maintenance structure that could be inspected easily inside and out, because rusting becomes a problem in the humid tropics. The top of the building consists of three elements: A drum-shaped garage on the top floor encloses a double-decker window-washing unit. From the wide garage, a cone tapers inward. Finally, a mast provides the visual transition from tower to sky. The 63.2-meter-tall mast has 14 meters of its length embedded in the cone frame, with the rest projecting above. The mast width tapers from 2.6 to 0.6 meter. At mid-height of the mast, a ball made of 14 pipes—each 300 millimeters in diameter that were curved into rings and attached together—symbolizes the 14 states of Malaysia, and a 1.9-meter ball sits at the top of the mast.

The window-washing garage and cone consist of a conventional steel-framed skeleton with attached stainless-steel facade panels. The narrow mast is made of stainless-steel panels, plates and bolts, which avoid corrosion and minimize maintenance. A single layer for both the facade and structural support eases inspection from inside ladders or external rigging. Using short panels facilitated lifting and assembly. The mast was assembled in small pieces within the building, then jacked up in two stages. This procedure protected workers and minimized the height of the crane required.

BRIDGE LEGS were lifted to their support bearings and strapped to each tower. Jacks then lifted the bridge ends to the skylobby floor. Next, workers elevated the bridge walkway (*left*). After welding these sections together, they swung out the bridge legs and attached them to the bottom of the structure (*center*). Bearings permit the bridge legs to flex as the towers move in the wind (*right*).







THORNTON-TOMASETTI ENGINEERS

ARCHITECTURAL DESIGN

Silhouettes against the Sky

As each tower ascends, it tapers in six gradations. In the upper sections the walls also tilt gently toward the center, completing the form and visually strengthening the *axis mundi*—the central vertical line of the skyscraper. The towers' pinnacles reach to the sky and reinforce the silhouette.

Throughout their development, the buildings maintained the basic form and image set out in the competition but also changed in many ways. The 12-pointed-star plan evolved into a 16-branched form; the towers acquired pinnacles and grew in height until they reached 451.9 meters, becoming the tallest buildings in the world.

The images that the towers create against the sky required detailed study. We proposed a pointed but pinnacleless design in the competition. The clients preferred a distinctly Malaysian top, one not derived from skyscrapers or church steeples. We experimented with many concepts, some of which were initially rejected, until the chosen pinnacle was developed.

From foundation to skybridge to pinnacle, construction is now complete, and occupants are moving in. At least for a while, the Petronas Towers will stand as the world's tallest skyscrapers. More significantly, the towers serve as worthy symbols of the culture and dynamism of this southeast Asian nation. SA

The Authors

CESAR PELLI, CHARLES THORNTON and LEONARD JOSEPH collaborated on the design of the Petronas Twin Towers. Pelli heads the architectural design firm of Cesar Pelli & Associates in New Haven, Conn., which, besides the Petronas Towers, designed the World Financial Center in New York City and the new Washington Airport terminal. He served as dean of the Yale University School of Architecture from 1977 to 1984. Earlier in his career, he worked in the offices of Eero Saarinen. In 1995 Pelli received the American Institute of Architects Gold Medal. Thornton is chairman and principal of Thornton-Tomasetti Engineers/LZA Group in New York City. He has spearheaded the engineering design of numerous projects, including One Liberty Place in Philadelphia, the United Center sports complex in Chicago and the United Airlines Terminal at O'Hare Airport in Chicago. He also assisted in the investigations into the roof collapse of the Hartford Civic Center and the Schoharie Creek Bridge failure. Thornton has taught at Manhattan College, Pratt Institute, Princeton University and Cooper Union. He co-authored with Joseph the book *Exposed Structure in Building Design*. Joseph is a vice president at Thornton-Tomasetti Engineers. He has been involved in the design of a variety of structures, among which are buildings, bridges, piers, parking decks, hangars and factories. His high-rise projects include the 50-story Chifley Tower in Sydney, Australia, and the 54-story One Mellon Bank Center in Pittsburgh.

Further Reading

THE PETRONAS TOWERS—THE TALLEST BUILDING IN THE WORLD. Hamdan Mohamad, Tiam Choon, Tarique Azam and Stephen Tong in *Habitat and the High-Rise: Tradition and Innovation*. Proceedings of the Fifth World Congress. Edited by Lynn S. Beedle. Council on Tall Buildings and Urban Habitat and the Dutch Council on Tall Buildings, 1995.

COSMIC PILLARS: PHILOSOPHY OF TALL BUILDINGS. Cesar Pelli in *Collected Papers of Habitat and the High Rise*. Council on Tall Buildings and Urban Habitat, 1996.

Defining Tall

The Council on Tall Buildings and Urban Habitat, a U.S.-based organization, has recently complicated the definition of what constitutes the world's tallest building. The committee decided on April 12, 1996, that the Petronas Towers deserve this designation, based on measurements from the ground to the top of the structure. Then, on July 10, 1997, it muddied the definition. In the council's new decision, Petronas became only one of three tallest buildings, retaining its status as world's highest building (to its "structural top"). The council also designated three new categories: height to tip of spire or antenna (held by One World Trade Center in New York City), height to top of roof, and height to highest occupied floor (the latter two records going to the Sears Tower in Chicago).

J. APICELLA Cesar Pelli & Associates

Building a

The largest public-works upgrade on earth calls for, among other things, a new airport, two world-class bridges and two submerged crossings of Victoria Harbor

by John J. Kosowatz
Photographs by Andy Ryan

Hong Kong's return to China in July sparked widespread speculation. People around the world offered their predictions as to how this tiny bastion of raw, unfettered capitalism would change once enveloped by the last great venue of communism. Despite the range of opinions voiced, however, most agreed that one thing would remain the same: Hong Kong would maintain its status as the major gateway to China.

One reason Hong Kong will continue to serve as an entry point to the mainland is the Airport Core Program, an ambitious $21-billion infrastructure project due for completion next year. Only in mercantile Hong Kong could a job of this magnitude be conceived, approved, financed, bid and largely completed in seven short years. The scope of work is enormous. Indeed, the Airport Core Program is the largest public-works upgrade ever undertaken.

It centers on building what will be the world's largest airport on Chek Lap Kok off Lantau Island, 25 kilometers west of Hong Kong's central business district. It also calls for 34 kilometers of new highways and railway lines, two massive bridges and two submerged crossings of Victoria Harbor to connect Chek Lap Kok to Hong Kong proper. In addition, contractors are erecting a new

HONG KONG, now under Chinese rule once more, will remain the major gateway to the mainland—in part thanks to its new airport at Chek Lap Kok.

New Gateway to China

town, called Tung Chung, near Lantau to house at least 200,000 people, most of whom will work at the airport at Chek Lap Kok.

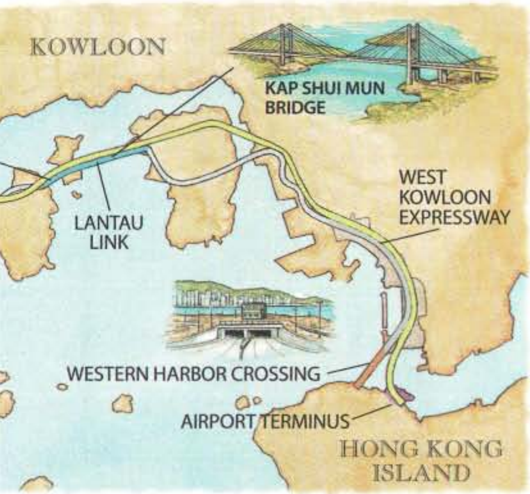
City planners first proposed the construction in the late 1980s, because Hong Kong was fast becoming one of the globe's busiest destinations. The existing airport, Kai Tak, could not be expanded because of its location in the middle of Kowloon: this district is highly congested, and airplanes must make harrowing approaches directly over buildings there. So, in 1989, the government approved plans for a new facility. A year later it formed the New Airport Projects Coordination Office, or NAPCO, which serves as the design and construction manager for the project's owners: the local government, Airport Authority Hong Kong, the Mass Transit Railway Corporation and Western Harbor Tunnel Company.

NAPCO officials, now headed by Tudor P. Walters, a vice president of Bechtel, a giant U.S. engineering firm and contractor, moved quickly on the design and planning. To keep on schedule and minimize costs, they decided to award mostly lump-sum, fixed-price contracts and to shun untried systems and technology. Methods that had not been tested elsewhere would have posed another problem in that contractors faced logistical extremes: the areas chosen for the airport at Chek Lap Kok

Chek Lap Kok

PLATFORM

Before any construction on the new airport could begin, contractors had to create for it a 1,248-hectare platform (*shown at right*). Chek Lap Kok was too small and hilly for the massive building and outstretched runways. A joint venture among Hong Kong's Gammon Construction, Japan's Nishimatsu Construction and several other firms won the first big award on this job, worth $1.2 billion, and they finished up in 1995, after only 41 months of work. To provide a base for the platform, Gammon/Nishimatsu leveled both Chek Lap Kok, which covers 302 hectares, and a smaller neighboring island to a height of six meters above sea level. They used reclaimed land to fill in the remainder. In all, the operation redistributed some 347 million cubic meters of rock and soil and monopolized much of the world's dredging fleet.



and the bridges were quite remote and lacked supply routes. And building sites in nearby Kowloon and Hong Kong were plagued with heavy traffic and limited space.

Engineering aside, NAPCO also had to raise the necessary funds. International power politics between China and the U.K. shadowed the program from the beginning. China, on the verge of regaining Hong Kong, remained unconvinced of the project's worth for a long while. But finally, in 1995, negotiators hammered out an astounding agreement: Hong Kong would fund 75 percent of the costs through an equity investment in the project, drawing on fiscal reserves of \$19.5 billion and \$57.7 billion initially set aside for foreign exchange trading. Loans would cover the remaining quarter. NAPCO rapidly began awarding contracts.

To date, China seems impressed with the results. Officials early this year approved the construction of a second 3,800-meter runway and of the terminal's northwest extension. This second job was not included in the core program; instead it was scheduled to occur during the project's second phase. And this time, Chinese officials approved funding the \$630-million northwest extension with a more standard 3:1 debt-to-equity ratio, reflecting their increased confidence in the investment. Walters of Bechtel says: "I believe they like our work."

DESIGN

Foster Asia, the Hong Kong–based operation of British architect Norman Foster, designed Chek Lap Kok's voluminous terminal. The initial plan, drawn up by the government, called for a series of linked, concrete buildings. But Foster Asia wanted more natural light and open space. The designers decided that a single building not only would look better but would be easier to assemble in the short time allowed. Also, Foster Asia felt that one building could more easily survive Hong Kong's seasonal typhoons.

The final design calls for some 350,000 cubic meters of concrete, together with 21,000 metric tons of steel for the roof and 2,400 metric tons of tubular steel to support the walls and glass panes. The building extends over 516,000 square meters, roughly in the shape of a wide-bodied airplane (*photograph at left*). The 490,000-square-meter concourse and main gate area stretch out for 1.3 kilometers, and the most remote gate areas split like a swallow's tail. All 39 fixed gates accommodate the world's largest passenger aircraft, the Boeing 747.

The terminal has eight levels. The first, for an automated people mover, includes a tunnel that is nearly one kilometer long, built by Gammon/Nishimatsu. A baggage hall, 320 by 160 meters, on the second level is closed to the public. The remaining six levels house a large retail complex, arrivals and departures, lounges and ticket counters. These floors have few interior walls, enabling visitors to see clearly throughout the terminal. Glass walls around the terminal's 4.4-kilometer perimeter offer views of the runways.

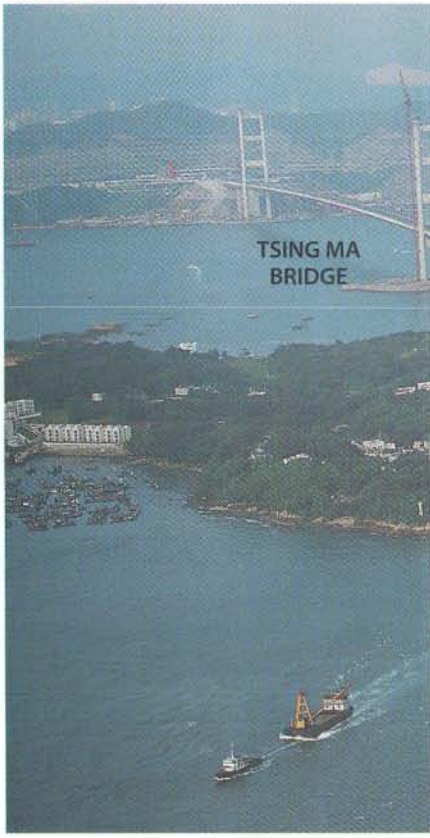
ROOF

Martin Manning, director of Ove Arup and Partners, headed the design team for the roof, which dips and rolls over the length of the building. A lightweight steel lattice, covered by a fabric membrane, gives the roof this wavy profile. The lattice's interlinked universal beams form a series of tubular, semicircular vaults—somewhat like the barrel vaults in some medieval churches. Skylights fit into each of the 129 roof modules, which are generally 36 by 36 meters in size and weigh 120 metric tons. They are supported by interior columns and also connect to the outer walls' mullions, those vertical bars that separate window units in a series. For this latter link, the engineers designed steel gaskets that allow the walls and the roof to shift horizontally and vertically in relation to each other—a flexibility that serves the structure well in strong winds.

CONSTRUCTION

The $1.29-billion contract awarded to realize Foster's plan went to a consortium of five British, Chinese and Japanese firms (BCJ)—China State Construction Engineering Corporation, Kumagai Gumi (HK), Maeda Corporation, Amec International Construction and Balfour Beatty. BCJ finished the job this fall, having overcome delays. Because of record rainfall in 1994 and difficult ground conditions on Chek Lap Kok, Gammon/Nishimatsu took longer than expected in turning the site over to BCJ. At the peak of construction on the terminal, BCJ had marshaled more than 1,600 workers.

Lantau Link



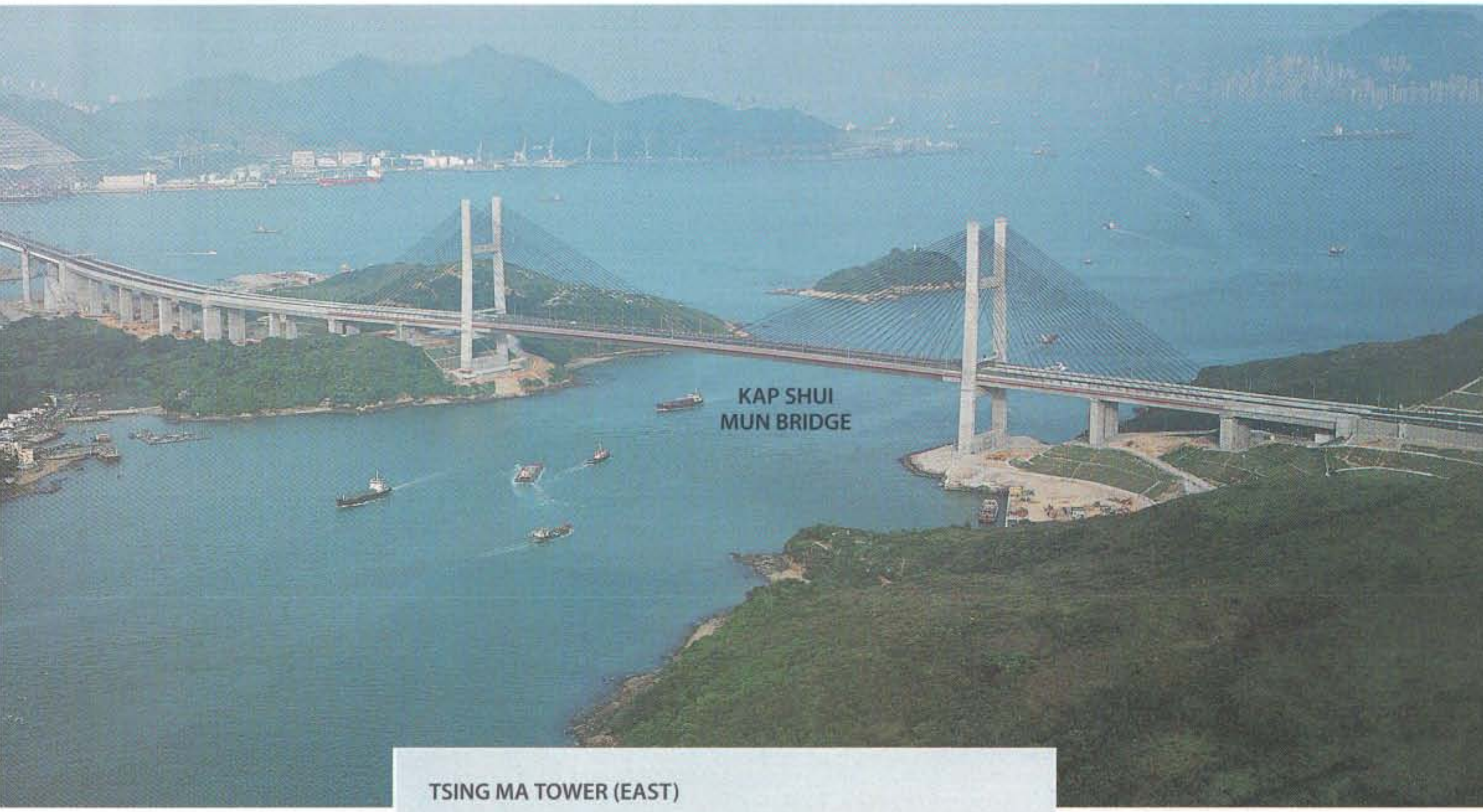
TSING MA BRIDGE

DESIGN

Already the Lantau Link—which joins Lantau Island to the mainland over a busy shipping channel leading to the Pearl River Delta—has become a national symbol for China. Its centerpiece is the double-decked Tsing Ma suspension bridge. At 2.17 kilometers long, Tsing Ma is the longest suspension bridge ever built to carry both rail and vehicular traffic. Under a $916-million contract, the Anglo-Japanese Construction Joint Venture of Trafalgar House Construction (Asia), Costain Civil Engineering, and Mitsui and Company began building Tsing Ma in 1992 and finished last year.

DECKS

Four years is an astonishingly short period for such an undertaking. South China's typhoons and Tsing Ma's location in a narrows called for a design that could withstand winds upward of 300 kilometers per hour. Fifty-one aerodynamically shaped, double-decked sections fit together in a sturdy hybrid of box-shaped structures and triangular frames, or trusses. Longitudinal vents built into each of the sections redirect



TSING MA TOWER (EAST)

strong winds and thereby provide greater stability.

Companies in Japan and the U.K. fabricated these steel deck sections and shipped them to China, just upstream of the project. Barges carried the assembled 1,000-metric-ton sections downstream, where a gantry crane hoisted them at low water. The sections are generally 40 meters wide, 36 meters long and 7.3 meters deep—accommodating six lanes of vehicular traffic on top and a railway line and two emergency traffic lanes on the bottom.

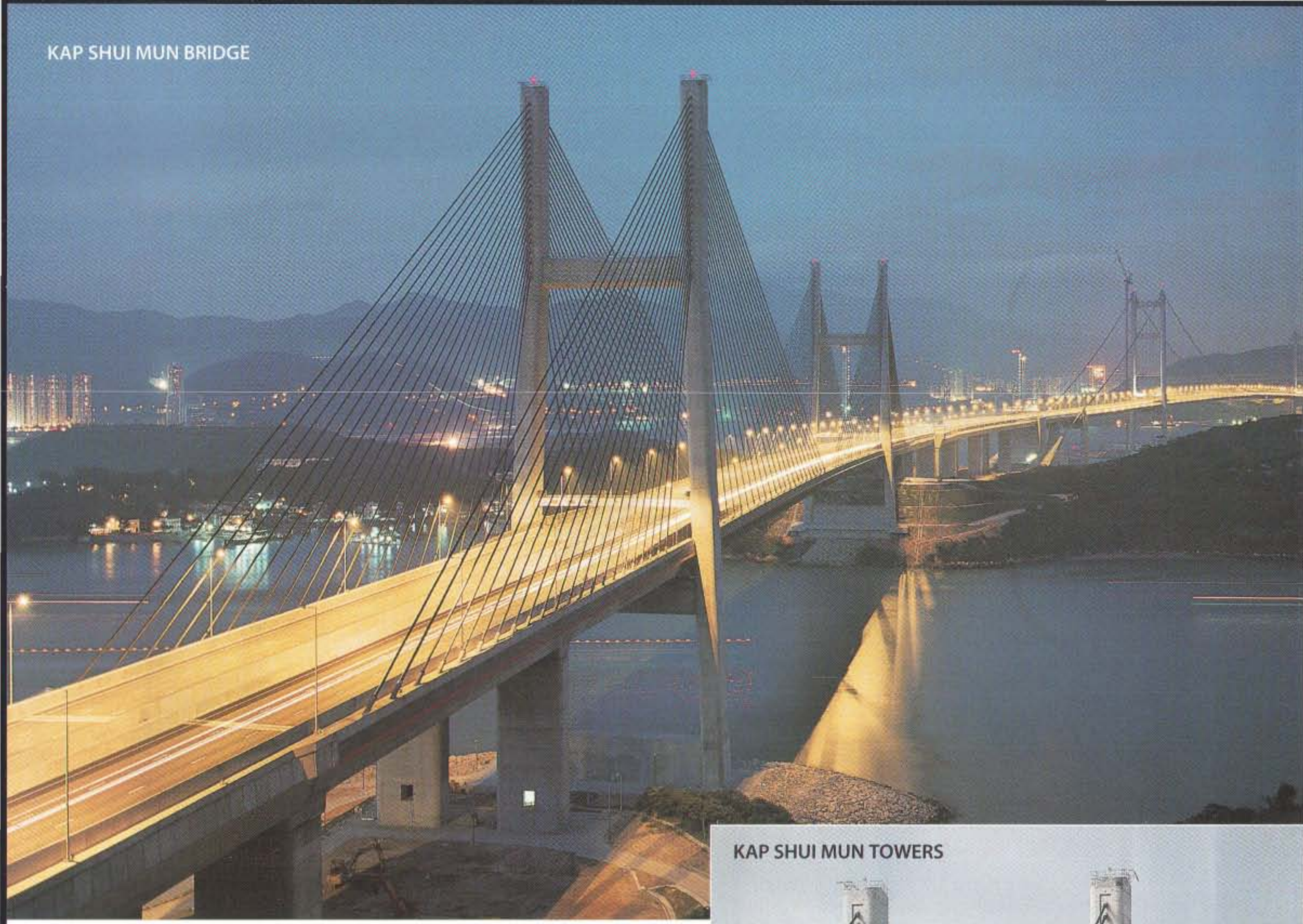
TOWERS

Two reinforced concrete towers, each 206 meters tall, bolster Tsing Ma's main span. Mitsui/Costain erected the towers using slip forms—in essence, temporary frames that can be easily moved as the concrete work progresses. The contractors completed the labor-intensive job in just three months. The eastern tower is secured in bedrock on Tsing Yi Island (*close-up above*). On the western end, the Ma Wan tower has a foundation that is tied into the bedrock below the channel. Workers built an artificial island around the foundation as added protection against shipping accidents.

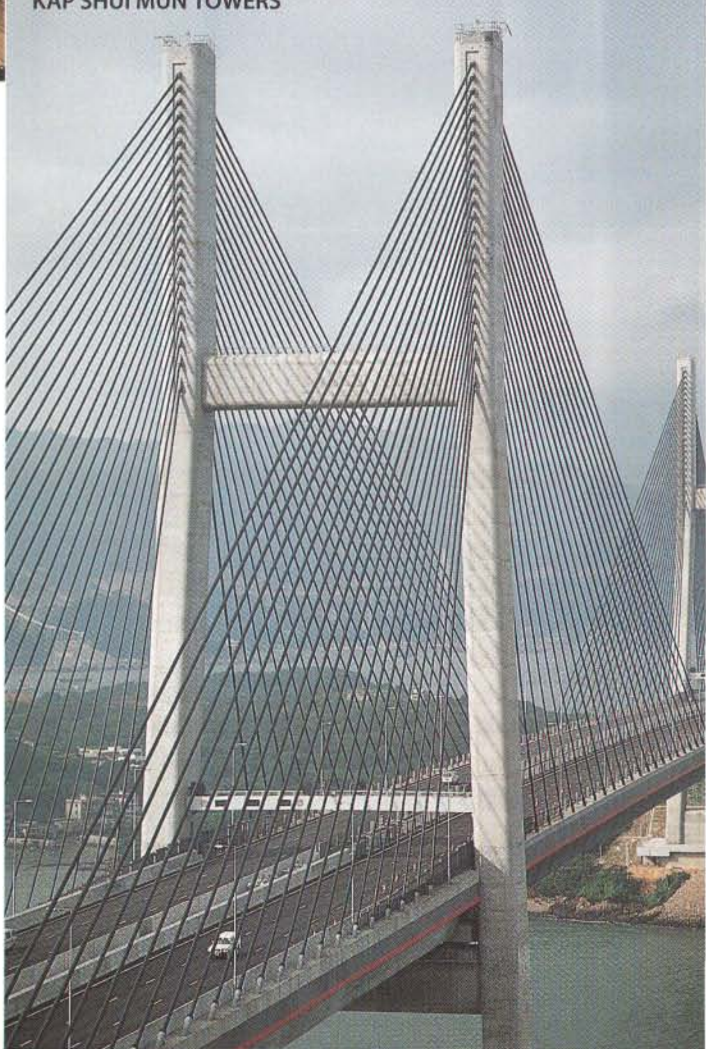
CABLES

The bridge is linked overhead by thick cables, 1.1 meters in diameter. Gurkhas, members of the British army, working on flimsy wood catwalks at great heights, spun together some 27,500 metric tons of galvanized steel wire to form these cables. The contractor chose the tactic, called aerial spinning, based on experience and cost.

Although aerial spinning can be dangerous, the firm felt that cables of this size would prove too cumbersome to form at the shop and then fit into place. The finished cables pass over steel saddles mounted on top of the towers, and gravity anchorages at either end pull them taut. Suspended cables, spaced 10 meters apart, hang from the main cables and hold up the 1,377-meter-long main span of Tsing Ma, as well as its 359-meter-long western span. Concrete piers lie underneath the slightly shorter eastern span.



KAP SHUI MUN BRIDGE



KAP SHUI MUN TOWERS

KAP SHUI MUN BRIDGE

TOWERS

The adjacent cable-stayed Kap Shui Mun Bridge—the next stop along the Lantau Link—boasts a main span that is 430 meters long. In total, it reaches across 750 meters and has one of the heaviest decks for its length in the world. The bridge was built under a $213-million contract by Kumagai Gumi (HK), Maeda Corporation, Yokogawa Bridge Corporation and Hitachi Zosen Corporation of Japan, another international joint venture. Kap Shui Mun relies primarily on two H-shaped towers, each 145 meters tall, for support.

DECKS

The bridge's decks adopt two different structural systems. The center of the main span is a double-box structure, formed from composite steel and concrete. The contractor cast the concrete upper and lower decks onto prefabricated steel webs at Lantau Island, floated them out and then hoisted them into position. In contrast, the side spans and the remainder of the center span consist of steel girders—four plates welded into a box section—that were reinforced with concrete and incrementally moved out into position from the towers on either side. Because the deck was 35.2 meters wide, workers needed to send out two girders at once, side by side, to match the span. They used concrete to join each pair at the bottom and struts to link the top slabs.

The launching noses—the front parts of the girders used to move the sections forward into position—were left in place and incorporated into the design. They serve as transition elements between the steel-composite main section and the concrete side sections. Where

these two structural systems join on either side reflects the depth of water in the Kap Shui Mun channel, which had to be deep enough to allow the heavy steel-composite units to be floated out. That point was 45 meters from each tower.

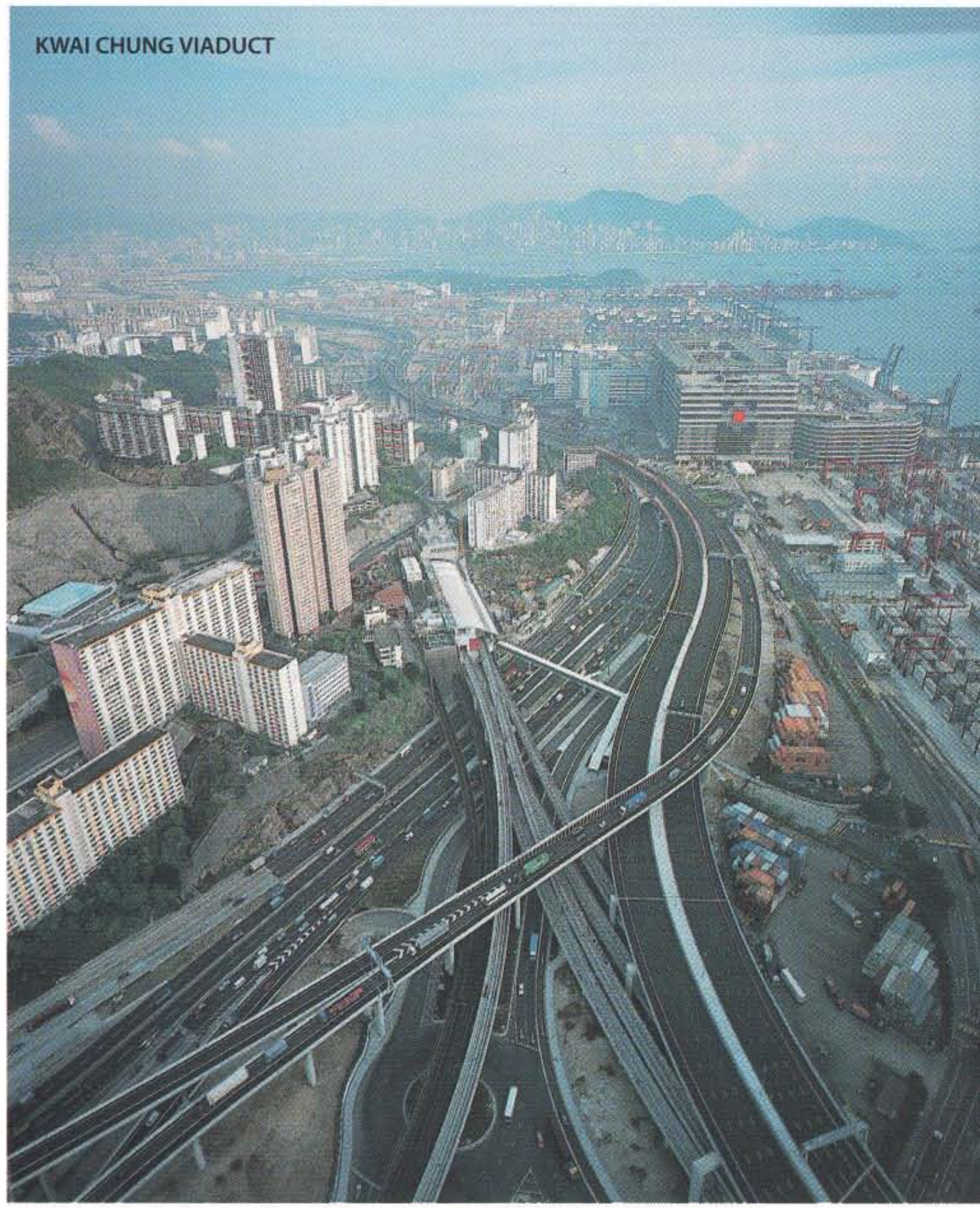
MA WAN VIADUCT

Neighboring Ma Wan Viaduct (*not shown*) is 504 meters long. The contractors built it by casting the concrete segments in place, using temporary falsework towers to support them until they were strong enough to stand on their own. Six spans, each 84 meters long, were cast in four 21-meter-long segments. These concrete beams were then compressed with wires, or post-tensioned; stretching wires taut through the concrete gives it added tensile strength to reduce cracking.

KWAI CHUNG VIADUCT

The West Kowloon Expressway's Kwai Chung Viaduct presented many difficulties. Because the viaduct must carry cars and the airport train for three kilometers, it required a number of different designs. "There is no typical column, and there are no typical beams," notes Ian J. Jones, the senior resident engineer for Scott Wilson Kirkpatrick, the highway department's consultant firm.

Workers formed the main road structure on top of precast, U-shaped concrete beams that were prestressed. To add strength, the concrete was compressed with heavily loaded wires or bars before it was laid. Then the concrete decks themselves were cast in place. The construction crew built the rail sections from precast concrete segments that were post-tensioned. These rail sections run across a series of columns, which rest on long, heavy posts bored into the ground and on foundations supported with barrettes, another type of pile. Much of the project is built on fill, a common practice in Hong Kong. French contractors had to dig 30 to 40 meters deep to find stable earth for anchoring the piles. Further complicating matters was that in many places workers needed to build the viaduct over 15 traffic lanes, which could not be shut down.

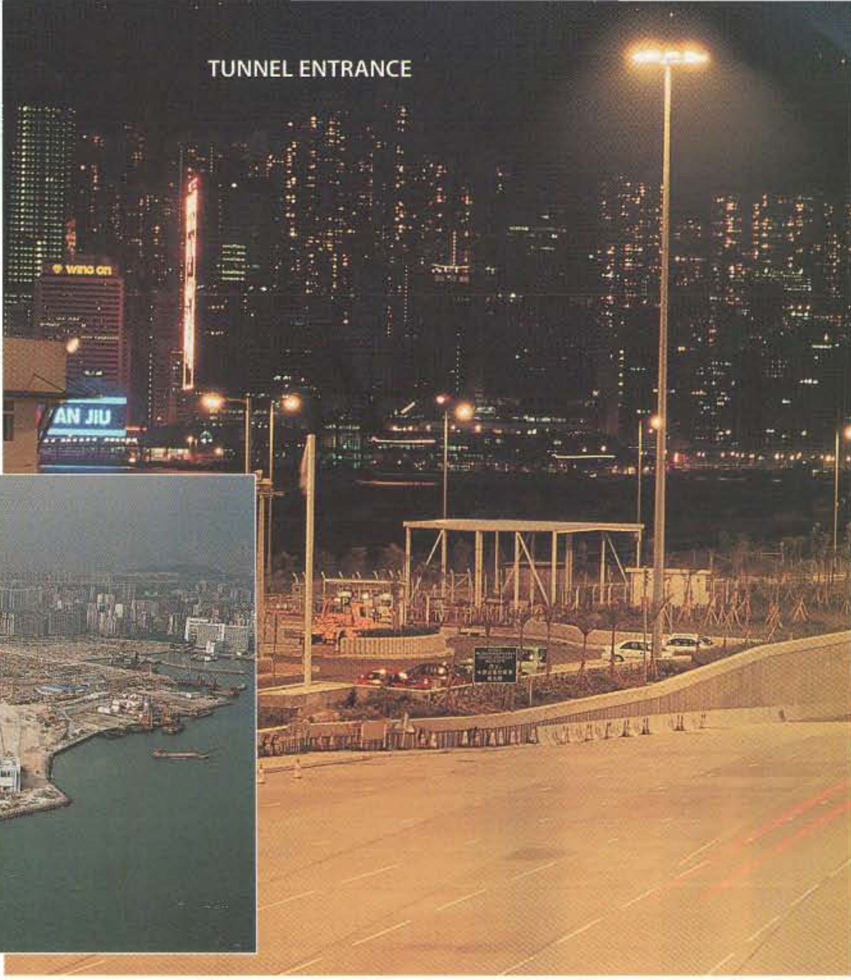


Western Harbor Crossing

A joint venture between Japan's Nishimatsu Construction and Kumagai Gumi (HK) won the $730-million contract to build the project's final leg, an immersed crossing of Victoria Harbor into central Hong Kong. The approaches to this two-kilometer tunnel on either side of the harbor are built on reclaimed land. The Hong Kong side proved more difficult because of large areas of marine mud. The contractor had to place diaphragm walls—used to separate the mud and provide stability under the foundation—down to depths of 40 meters. The Kowloon side provided better fill. For this reason, the contractor was able to secure the approach using re-

inforced concrete box sections that were cast in place.

A seaside quarry on the other side of Hong Kong Island formed the giant tube segments for the tunnel itself. When the segments were assembled, the quarry was flooded, and the pieces were floated out and then towed to the site. Workers at the same location built the sections for the rail tunnel. So that the segments could be sunk and attached to a trench-dredging machine on the harbor bottom, they were all fitted with ballast tanks and handlelike lugs. Once the segments were lowered into the trench, horizontal jacks drew them into position and created a seal.


TUNNEL ENTRANCE

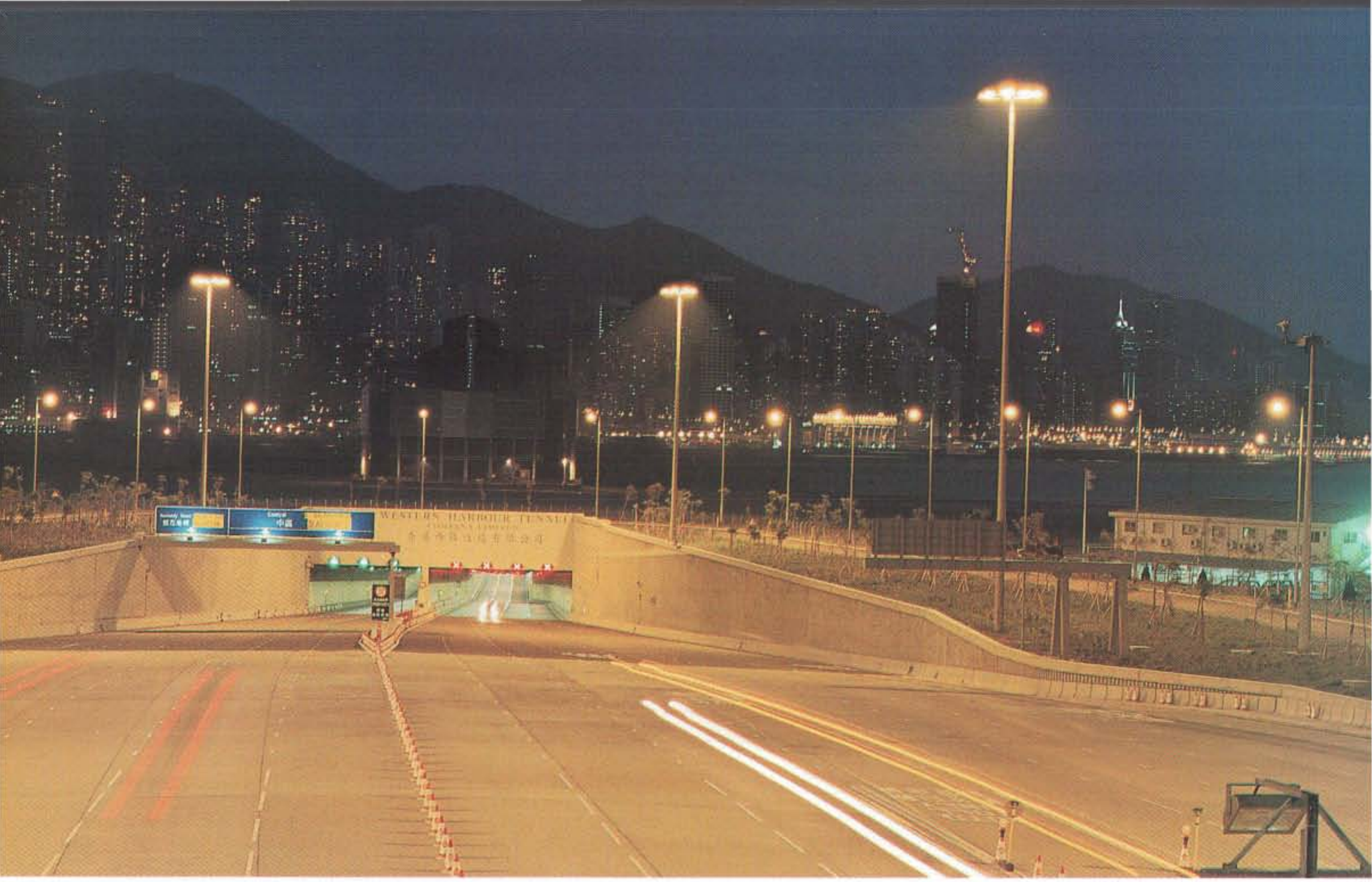

WESTERN HARBOR CROSSING

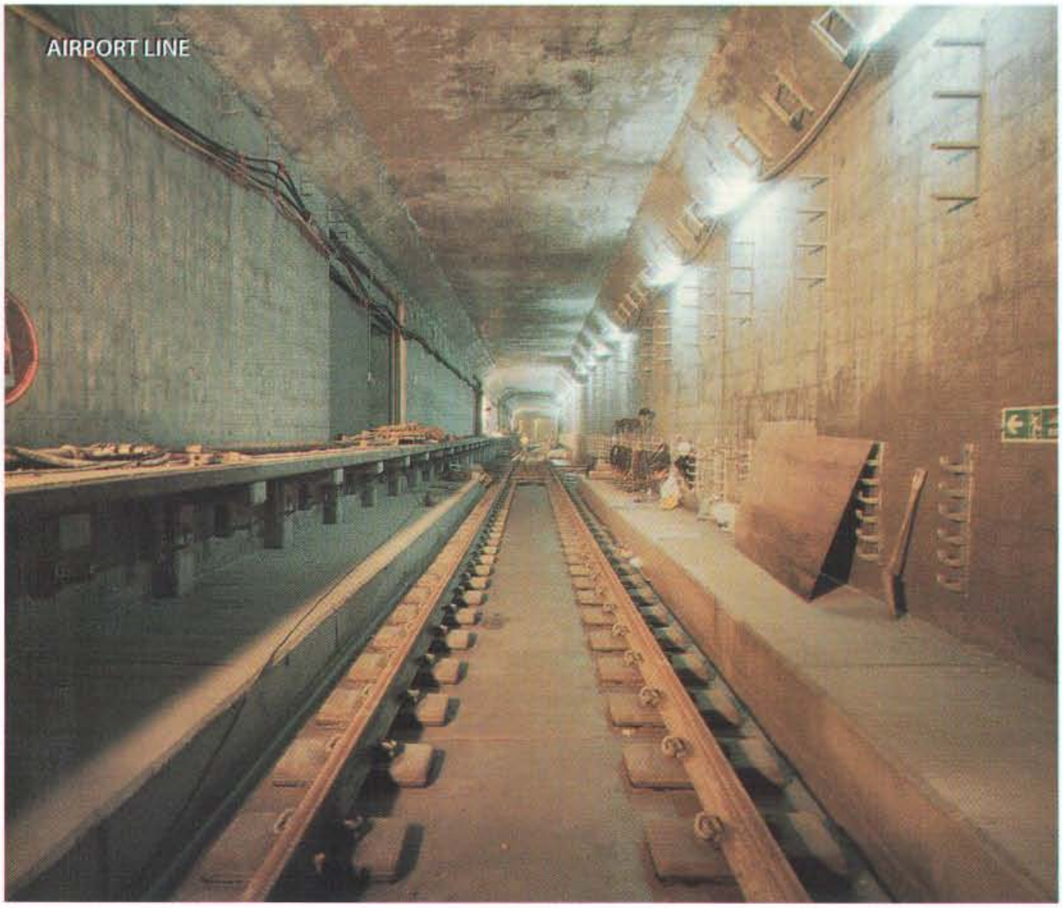
Airport Line Terminus

The $528-million terminus for the airport line sits on a six-hectare site in front of Exchange Place, home of the Hong Kong Stock Exchange. It contains a five-level underground station, numerous rail tunnels and a building with a steel roof that extends for 25 meters. The most complex feature of the structure is a $93-million underground pedestrian walkway that links the terminus to the Mass Transit Railway Corporation's existing central station.

The 300-meter-long tunnel snakes directly below the stock exchange. Thus, workers from Japan's Aoki Corporation must tunnel between the piles of


CONNAUGHT ROAD





the exchange's foundation, taking precautions not to cut its fiber-optic link and other service lines. They must furthermore take care not to make any adjustments that might cause the exchange building to settle, now or in the future. The path also crosses under Connaught Road, one of Hong Kong's busiest thoroughfares. Despite these difficulties, though, the railway line is scheduled to open in June 1998, two months after the airport at Chek Lap Kok begins operations.

JOHN J. KOSOWATZ is assistant managing editor at Engineering News-Record.

More information on the airport at Chek Lap Kok is available at http://www.hkairport.com on the World Wide Web.

Do We Still Need Skyscrapers?

The Industrial Revolution made skyscrapers possible. The Digital Revolution makes them (almost) obsolete

by William J. Mitchell

Our distant forebears could create remarkably tall structures by exploiting the compressive strength of stone and brick, but the masonry piles they constructed in this way contained little usable interior space. At 146 meters (480 feet), the Great Pyramid of Cheops is a vivid expression of the ruler's power, but inside it is mostly solid rock; the net-to-gross floor area is terrible. On a square base of 230 meters, it encloses the King's Chamber, which is just five meters across. The 52-meter spiraling brick minaret of the Great Mosque of Samarra does not have any interior at all. And the 107-meter stone spires of Chartres Cathedral, though structurally sophisticated, enclose nothing but narrow shafts of empty space and cramped access stairs.

The Industrial Revolution eventually provided ways to open up the interiors of tall towers and put large numbers of people inside. Nineteenth-century architects found that they could achieve greatly improved ratios of open floor area to solid construction by using steel and reinforced concrete framing and thin curtain walls. They could employ mechanical elevators to provide rapid vertical circulation. And they could integrate increasingly sophisticated mechanical systems to heat, ventilate and cool growing amounts of interior space. In the 1870s and 1880s visionary New York and Chicago architects and engineers brought these elements together to produce the modern skyscraper. Among the earliest full-fledged examples were the Equitable Building (1868–70), the Western Union Building (1872–75) and the Tribune Building (1873–75) in New York City, and Burnham & Root's great Montauk Building (1882) in Chicago.

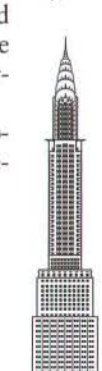
These newfangled architectural contraptions found a ready market because they satisfied industrial capitalism's growing need to bring armies of office workers together at locations where they could conveniently interact with one another, gain access to files and other work materials, and be supervised by their bosses. Furthermore, tall buildings fitted perfectly into the emerging pattern of the commuter city, with its high-density central business district, ring of low-density bedroom suburbs and radial transportation systems for the daily return journey. This centralization drove up property values in the urban core and created a strong economic motivation to jam as much floor area as possible onto every available lot. So as the 20th century unfolded, and cities such as New York and Chicago grew, downtown skylines sprouted higher while the suburbs spread wider.

But there were natural limits to this upward extension of skyscrapers, just as there are constraints on the sizes of living organisms. Floor and wind loads, people, water and supplies must ultimately be transferred to the ground, so the higher you go, the more of the floor area must be occupied by structural supports, elevators and service ducts. At some point, it becomes uneconomical to add additional floors; the diminishing increment of usable floor area does not justify the increasing increment of cost.

Urban planning and design considerations constrain height as well. Tall buildings have some unwelcome effects at ground level; they cast long shadows, blot out the sky and sometimes create dangerous and unpleasant blasts of wind. And they generate pedestrian and automobile traffic that strains the capacity of surrounding streets. To control these effects, planning authorities typically impose limits on height and on the ratio of floor area to ground area. More subtly, they may apply formulas relating allowable height and bulk to street dimensions—frequently yielding the stepped-back and tapering forms that so strongly characterize the Manhattan skyline.

The consequence of these various limits is that exceptionally tall buildings—those that really push the enve-

BRYAN CHRISTIE

Great Pyramid of Cheops **Built** circa 2600 B.C. **Height** 146 meters **Egypt**

Minaret of Samarra **Built** 9th century **Height** 52 meters **Iraq**

Chartres Cathedral **Built** 13th century **Height** 107 meters **France**

Equitable Building **Built** 1870 **Height** 43 meters **New York**

Western Union Building **Built** 1875 **Height** 70 meters **New York**

Tribune Building **Built** 1875 **Height** 79 meters **New York**

Chrysler Building **Built** 1930 **Height** 319 meters **New York**

lope—have always been expensive, rare and conspicuous. So organizations can effectively draw attention to themselves and express their power and prestige by finding ways to construct the loftiest skyscrapers in town, in the nation or maybe even in the world. They frequently find this worthwhile, even when it does not make much immediate practical sense.

There has, then, been an ongoing, century-long race for height. The Chrysler Building (319 meters) and the Empire State Building (381 meters) battled it out in New York in the late 1920s, adding radio antennas and even a dirigible mooring mast to gain the last few meters.

The contest heated up again in the 1960s and 1970s, with Lower Manhattan's World Trade Center twin towers (417 meters), Chicago's John Hancock tower (344 meters) and finally Chicago's gigantic Sears Tower (443 meters). More recently, Cesar Pelli's skybridge-linked Petronas Twin Towers (452 meters) in Kuala Lumpur have—for a while at least—taken the title of world's tallest building.

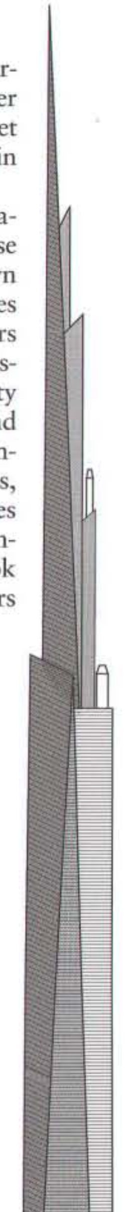
Along the way, there were some spectacular fantasy entrants as well. In 1900 Désiré Despradelle of the Massachusetts Institute of Technology proposed a 457-meter "Beacon of Progress" for the site of the Chicago World's Fair; like Malaysia's Petronas Towers of almost a century later, it was freighted with symbolism of a proud young nation's aspirations. Despradelle's enormous watercolor rendering hung for years in the M.I.T. design studio to inspire the students. Then, in 1956, Frank Lloyd Wright (not much more than five feet in his shoes and cape) topped it with a truly megalomaniac proposal for a 528-story, mile-high tower for the Chicago waterfront.

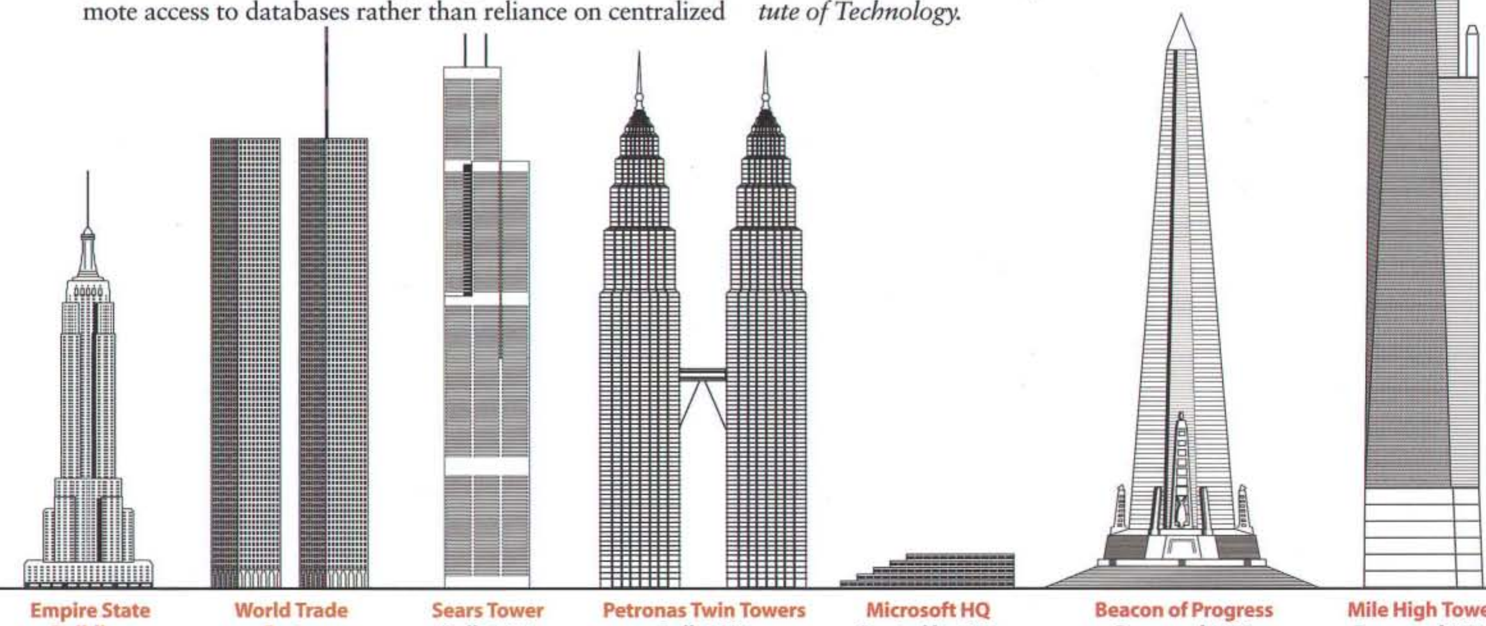
While this race has been running, though, the burgeoning Digital Revolution has been reducing the need to bring office workers together, face-to-face, in expensive downtown locations. Efficient telecommunications have diminished the importance of centrality and correspondingly increased the attractiveness of less expensive suburban sites that are more convenient to the labor force. Digital storage and computer networks have increasingly supported decentralized remote access to databases rather than reliance on centralized paper files. And businesses are discovering that their marketing and public-relations purposes may now be better served by slick World Wide Web pages on the Internet and Superbowl advertising spots than by investments in monumental architecture on expensive urban sites.

We now find, more and more, that powerful corporations occupy relatively unobtrusive, low- or medium-rise suburban office campuses rather than flashy downtown towers. In Detroit, Ford and Chrysler spread themselves amid the greenery in this way—though General Motors has bucked the trend by moving into the lakeside Renaissance Center. Nike's campus in Beaverton, Ore., is pretty hard to find, but www.nike.com is not. Microsoft and Netscape battle it out from Redmond, Wash., and Mountain View, Calif., respectively, and—though their logos, the look and feel of their interfaces, and their Web pages are familiar worldwide—few of their millions of customers know or care what the headquarters buildings look like. And—a particularly telling straw in the wind—Sears has moved its Chicago workforce from the great Loop tower that bears its name to a campus in far-suburban Hoffman Estates.

Does this mean that skyscrapers are now dinosaurs? Have they finally had their day? Not quite, as a visit to the fancy bar high atop Hong Kong's prestigious Peninsula Hotel will confirm. Here the washroom urinals are set against the clear plate-glass windows so that powerful men can gaze down on the city while they relieve themselves. Obviously this gesture would not have such satisfying effect on the ground floor. In the 21st century, as in the time of Cheops, there will undoubtedly be taller and taller buildings, built at great effort and often without real economic justification, because the rich and powerful will still sometimes find satisfaction in traditional ways of demonstrating that they're on top of the heap. SA

WILLIAM J. MITCHELL is dean of the School of Architecture and Planning at the Massachusetts Institute of Technology.





Empire State Building
Built 1931
Height 381 meters
New York

World Trade Center
Built 1972
Height 417 meters
New York

Sears Tower
Built 1974
Height 443 meters
Chicago

Petronas Twin Towers
Built 1997
Height 452 meters
Kuala Lumpur, Malaysia

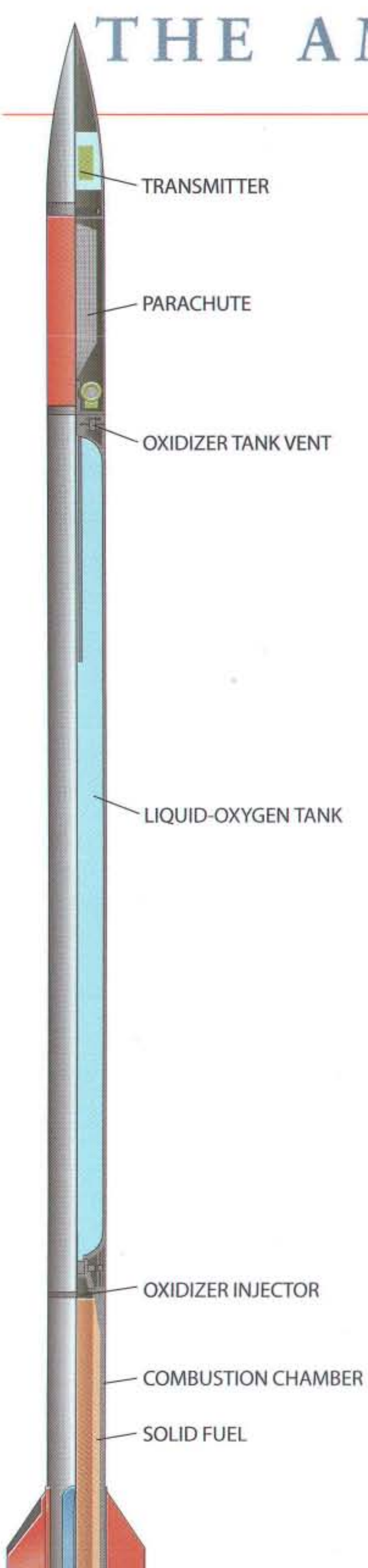
Microsoft HQ
Started in 1986
Height 20 meters
Redmond, Wash.

Beacon of Progress
Proposed 1900
Never built
Height 457 meters
Planned for Chicago

Mile High Tower
Proposed 1956
Never built
Height 1,609 meters
Planned for Chicago

THE AMATEUR SCIENTIST

by Shawn Carlson



MICHAEL GOODMAN

HYPERION I used a hybrid rocket motor to capture the altitude record.

Taking Back the Final Frontier

In my youth, nothing excited me quite as much as spaceflight. When Neil Armstrong's boots first pressed into the lunar soil in 1969, I was right there with him, like millions of other children, dreaming of the day when I could step beyond my imagination and make the trip for real. By age 11, I was a passionate rocketeer, building fleets of model rockets and launching them every other Sunday in the parking lot of the local baseball stadium. But I burned out on model rocketry in my early teens when I realized that the National Aeronautics and Space Administration owned the monopoly on getting to space. Amateurs could not hope to compete, and, indeed, few even tried.

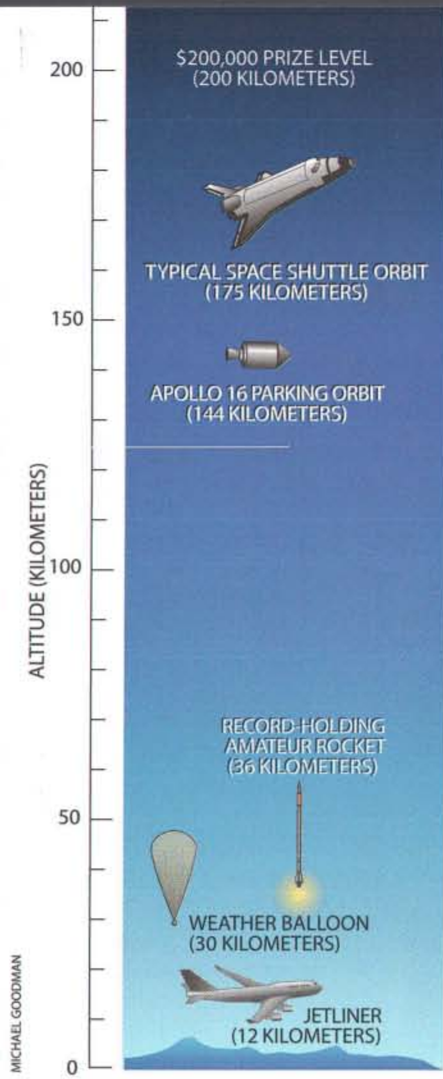
Today, however, amateur rocketry is undergoing a renaissance. Exciting new developments in ultralightweight materials and powerful rocket motors now give amateurs all the tools they need to venture toward the final frontier. And people are responding. At least one rocketeer's creation recently reached an altitude of 36 kilometers, and other attempts to fly small payloads to 100 kilometers are tugging on the coattails of space with rockets that cost just a few thousand dollars.

To hasten the progress of such enterprises, a nonprofit group called the Foundation for the International Nongovernmental Development of Space (FINDS), based in Washington, D.C., has just announced a competition that could spark a small revolution: FINDS will pay $200,000 to the first amateur team that can loft a two-kilogram payload to an altitude of 200 kilometers. (The second group to accomplish this feat will win $50,000.) That announcement has started a citizens' space race, one that is open to anyone with the desire to participate. This month's column points the way for interested amateurs to get involved quickly and safely.

Safety is an important concern. A rocket motor, after all, burns a volatile fuel together with a separate oxidizing agent to produce gases at dangerously high temperatures and pressures. These gases blow through a nozzle at the rocket's tail and, in one of the most visible displays of Newton's law of action and reaction, propel the rocket forward. The fuel and oxidizer may be liquid or solid, or a combination of both. The space shuttle's main engines, for instance, combust liquid hydrogen with liquid oxygen, whereas its solid-rocket boosters burn a stiff matrix of synthetic rubber and aluminum powder, with ammonium perchlorate grains as the oxidizer.

Much smaller solid-propellant motors operating on the same principle are commercially available from several companies. These devices range in price from a few hundred dollars to more than $100,000. Potent motors can also be made at home for only a small fraction of the cost to industry; a few thousand dollars might fund one large enough to go after the FINDS prize. But building your own motors could be lethal without expert guidance. Thank goodness, therefore, for the Reaction Research Society, an amateur group headquartered in Los Angeles. That organization, which has been developing and testing rocket motors of all kinds since 1943, boasts a perfect safety record. It offers a complete course in solid-rocket motor construction, and anyone who wants to survive the challenge of hands-on motor making would be well advised to take it. The three-day course costs $475 and culminates with the students firing their homebuilt rocket motors on the society's testing range, which is located in California's Mojave Desert.

If you want to experiment with liquid-fueled rockets, check out the Pacific Rocket Society, also run from southern California. Its members have been experimenting with liquid propellants for more than 50 years and can give you practical instruction with these kinds of engines. They are currently assembling their most powerful creation ever, a two-stage, 10-meter, 300-kilogram monster dubbed the Exotron. Built by the society's president, Roderick Milliron, and



***HIGH-FLYING CRAFT** usually travel well below the 200-kilometer altitude needed to earn a $200,000 prize.*

Ian Furlong, the Exotron might become the first amateur rocket to fly into history. They anticipate shooting for the FINDS prize in January 1998.

Constructing a heavy-duty motor is only part of the challenge. The winning rocket must be stable enough to avoid tumbling over in the first few seconds, when it is traveling too slowly for the stabilizing fins to do their job. Also, it must not veer too far from the desired flight path even as it plows through the powerful winds in the upper atmosphere. And it must survive the vibration and stress of flight. The best way to design a vehicle that can take on these rigors is to learn from the experts.

One source of help is the Tripoli Rocketry Association in Bessemer, Ala. Tripoli is perhaps the world's premiere rocketry organization. It schools and certifies its members in the art of making and safely flying high-powered rockets. Tripoli organizes regular gatherings, at which devotees of the sport fire their often spectacular handiwork at so-called LDRS launches (the acronym stands for "large and dangerous rocket ships").

What strikes me most on reading Tripoli's magazine, *High Power Rocketry*, is that so many firms sell sophisticated rocketry supplies. One of these companies, Rocketman Enterprises, in South Bloomington, Minn., is headed by the most colorful rocketeer I know: Ky Michaelson is a 59-year-old stuntman who attaches rockets to everything from skates to motorcycles. This past summer he attempted to send a two-stage, 136-kilogram vehicle to 192 kilometers, just shy of the FINDS target. The second stage failed, but the first stage reportedly accelerated to Mach 2.6 (2.6 times the speed of sound) and topped out at nearly 24 kilometers.

The current record for verified altitude obtained by an amateur rocket is owned by the Hyperion I and its designer, Korey Kline. Kline, a Tripoli member for more than 15 years, is director of research at Environmental Aeroscience Corporation in Miami. His company specializes in fabricating rocket motors for commercial and hobby use. Kline is an expert on what are known as hybrid motors, which combine solid fuel with fluid oxidizer. His creation, a cylindrical tube 15 centimeters wide by 5.5 meters tall, was powered by such a hybrid. Launched on January 7, 1997, from the NASA Goddard Space Flight Center's Wallops Flight Facility, the Hyperion I devoured its 48 kilograms of propellant in just 15 seconds, passing Mach 3 before coasting upward to 36 kilometers. Kline is currently building a beefed-up version, the Hyperion II, to aim for the FINDS prize. If all goes well, he intends to launch late in 1998.

A fundamental problem that Kline and his rockets face is atmospheric drag, which increases drastically as the velocity rises (drag is in fact proportional to velocity squared). By achieving its maximum velocity quickly, while it is still low in the atmosphere, Hyperion I expended a great deal of energy battling the air around it, energy that would otherwise have lofted the rocket much higher.

John M. Powell of JP Aerospace in Davis, Calif., sidesteps this problem by avoiding most of the atmosphere altogether. Powell is a computer programmer and lifelong space enthusiast who delights in his group's motto: "America's other space program." Powell and his companions have spent much of the past 18 years systematically developing an ingenious system to launch rockets from weather balloons, a trick pioneered by NASA. Although Powell's tests have so far been restricted to low altitudes, he believes he can ultimately launch his existing rocket from 30 kilometers (about 100,000 feet) to a height of 80 kilometers. He intends to capture the FINDS prize by scaling up his operation and then to use the money to develop a system that can put small payloads into orbit.

Although the FINDS prize is meant to stimulate advances in rocket technology, the new amateur space race also needs electrical engineers, radio hobbyists and science enthusiasts of all stripes who want to help build and fly useful payloads. After all, without proper instruments, amateur rockets—whatever altitudes they may reach—will remain little more than especially flashy Roman candles. So if you think you have something to contribute, find a rocketry group and get involved; there should be plenty of them out there vying for the FINDS prize. Even the Society of Amateur Scientists is gearing up to join this new amateur race into space. SA

To get involved, consult any of the societies listed below or the Society for Amateur Scientists's World Wide Web site at www.thesphere.com/SAS/. You may also write the society at 4735 Clairemont Square, Suite 179, San Diego, CA 92117, call (619) 239-8807 or leave a message at (800) 873-8767.

Resources

The Foundation for the International Nongovernmental Development of Space (FINDS), 2000 L Street, N.W., Suite 200, Washington, DC 20036; (800) 78-SPACE.

Reaction Research Society, P.O. Box 90306, World Way Postal Center, Los Angeles, CA 90009; (310) 515-6458; www.rrs.org/

Pacific Rocket Society, P.O. Box 241993, Los Angeles, CA 90024; (805) 824-1662; cyberplex@aol.com

Tripoli Rocketry Association, P.O. Box 280, Bessemer, AL 35021-0280; (205) 424-8357; www.tripoli.org/

MATHEMATICAL RECREATIONS

by Ian Stewart

Cat's Cradle Calculus Challenge

Knots, links and their relatives have fascinated mathematically minded people for millennia. But it was only in the 1920s that mathematicians began to slash through the elusive challenge of characterizing knots, distinguishing different knots and generally understanding what it is that makes knots knotted and links linked. Their investigations led to the creation of topology, a powerful tool of today's mathematics.

The past decade has seen dramatic developments in knot theory—most of all, Vaughan Jones's invention of what is now called the Jones polynomial, an algebraic formula associated with a knot [see "Knot Theory and Statistical Mechanics," by Vaughan F. R. Jones; Scientific American, November 1990]. If two knots have different Jones polynomials, then they are topologically distinct, meaning that one cannot be continuously deformed into the other. Such "knot invariants" have been found before, but the Jones polynomial was the first of a new generation of superinvariants, far better at the job than their predecessors.

Even the Jones polynomial, however, cannot tell us everything we want to know about knots and links. These objects give rise to some questions that do not even belong to topology—and that's what I want to discuss this month. Recreational mathematics has a habit of throwing out challenges, but this time around I'm going to go further and start from a recreation that lies, at best, on the margins of mathematics. It is the well-known childhood game of cat's cradle.

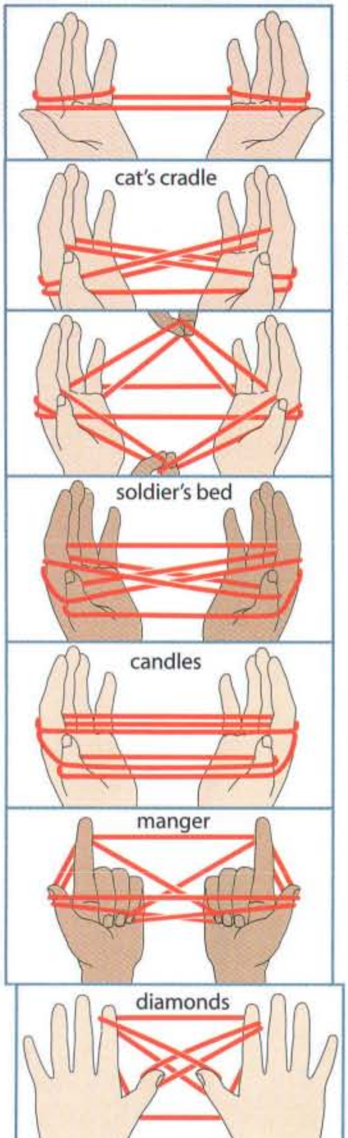
I say "well known," but many people are unaware of how rich the game is. The complete cat's cradle sequence involves eight separate figures. Innumerable other figures can be constructed in the same general manner, with a simple loop of string draped and twisted between the fingers of two hands. The game illustrates the extent to which the topology of a loop of string—the number of knots, for instance—fails to capture its richer geometric properties, such as shape.

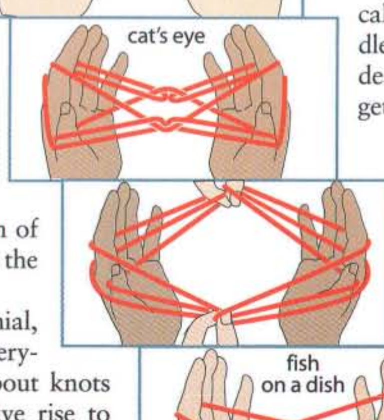
It ought to be possible to devise a neat calculus of cat's cradle, an algebra that describes how to get from the initial uninteresting loop to more significant shapes by making standard moves of various kinds. One of the earliest successes in studying knots and their like was the theory of braids, created by Emil Artin. A braid is a system of strings (or curves) that initially run parallel to one another. More generally, the strings are permitted to wind around one another, like braids in hair. Artin developed a kind of braid algebra, which could distinguish topologically inequivalent braids. If two braids had the same algebraic formula, they were equivalent; if they had different formulas, they were inequivalent. Artin's ideas were, to some extent, the inspiration for Jones's.

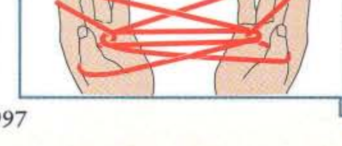
In several respects, cat's cradle figures are similar to braids. Instead of the two ends of a braid, we have a set of fingers around which the string is to be draped. The moves allowed in cat's cradle are richer, however, than those used by Artin: for example, several strings can wrap around a given finger. This is one reason why braid algebra is inadequate to describe cat's cradle figures. Another—which may be less significant than it first seems—is that all cat's cradle figures are topologically equivalent to a single unknotted loop.

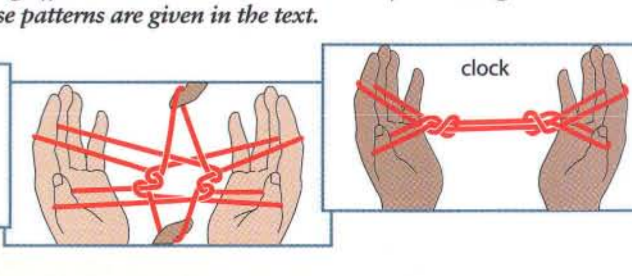
I suspect that this problem can be got round by considering not just the string but how it winds around the fingers. Yet another complication can be seen in the standard version of the childhood game: permissible moves include a second person reaching into the middle of the figure and picking it up on their own hands—trading one shape on one person's hands for a different shape on the other's.

To make a cat's cradle, you need a









EIGHT FIGURES form the complete sequence of cat's cradle. The game involves two persons, Angela (lighter color) *and Bill* (darker color), *who lift a looped loop of string off each other's hands. Instructions for creating these patterns are given in the text.*

piece of soft, smooth string about three feet long, with its ends tied to form a closed loop, and a friend. Suppose Angela and Bill take turns removing the loop of string from each other's hands. First, Angela sets up the cradle [*see illustration on opposite page*]. There is one basic movement in the sequence, used at almost every step, and this is the first place it arises. Bill stands on, say, Angela's right. Looking down into the figure, he can see two crossings: he picks these up, one in each hand, and pulls them apart. Then he draws the strings away from the center of the figure, over the outside edge, down, inward and back up through the gap in the center.

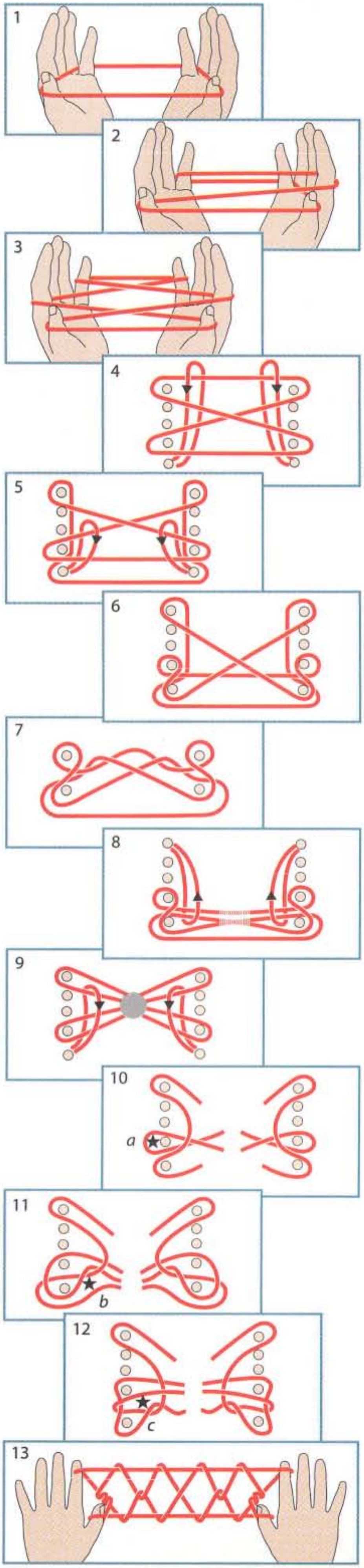
As Bill draws his hands apart and separates his thumb and index finger, Angela loosens the loops from her fingers and lets them slip off. Now Bill can take the new figure onto his hands. This stage is called the soldier's bed. If Angela now repeats exactly the same moves, starting from this second figure, she creates the third shape, known as the candles.

To get from the candles to the fourth figure requires a new movement. Bill first draws aside one, then the other, inner string (on opposite sides) with his little fingers and passes the thumb and index finger into the center of the figure from below. This is similar to the basic move, but no crossed strings are carried. Finally, Bill opens up his thumb and forefinger and grips the loops around his little fingers by bending the fingers over. The result is the manger. As a mathematical aside, the manger is just like the cat's cradle, but upside down.

From the manger, another repetition of the basic move, also performed upside down (take the crossings from below rather than above), leads to the soldier's bed, but upside down. Traditionally this fifth shape is called the diamonds. Yet another repetition of the basic move, this time the usual way up, produces the cat's eye. Picking up slightly differently and drawing the hands back without swooping back underneath to the center leads to the fish on a dish.

The final shape is more elusive. Bill uses his little fingers to separate the central strings and then picks up the crossings in the usual manner. Next, he turns his thumbs and index fingers inward and upward, to get the eighth shape, the clock. I have no idea why the shape

ILLUSTRATIONS BY DANA BURNS-PIZER



has this name: Maybe a reader can enlighten me?

If you use different moves, you can change the order of the sequence—for instance, by going straight from the cradle to the candles or from the soldier's bed to the cat's eye. An effective cat's cradle calculus ought to be able to explain all such variations. For instance, two specific moves might "commute"—yield the same result even if their order is reversed. The objective of the theory should be to describe the actual forms of the string figures, not just their topology. A good start would be a compact notation for "positions" of the loop relative to fingers and for standard moves, such as "pick up a loop from the right hand using the middle finger of the left hand," or whatever.

Interesting shapes can be made by a single person, too. In attempting to develop a cat's cradle calculus, it might be best to start with this case. To show you how fascinating the possibilities can be, I'll describe a figure known as Indian diamonds. It starts in a very similar way to cat's cradle, but not quite [*see illustration at left*]. Begin with the standard loop (*1*), then pick up the string that runs across the left palm with the right index finger (*2*) and repeat with the other hand (*3*). Next, slip the loop off your thumbs by bending them in toward each other and gently but steadily pulling your hands apart. Twist your hands so that your palms face outward. Pass your thumbs forward under all the strings, hook them over the little-finger string and twist your hands back, drawing the little-finger string toward you (*4*). This motion is more natural than it sounds, and if you try it, you'll find that the string you pick up is the "obvious" one for this method.

Next, pass your thumbs over the top of the string immediately in front of them, then underneath the next strings to pick them up with the backs of the thumbs (*5*), to get the subsequent shape (*6*). Slip the loops off your little fingers by bending the fingers and pulling your hands gently apart. The result (*7*) is rather tangled, but from here on out it gets simpler. Bend your little fingers toward you, turning the hands over if you wish, and bend the fingers over the first string they meet (from the index fingers) and under the next string after that (from the thumbs). Now straighten the little fingers (*8*).

At this stage there are two loops on each thumb, and you should free these, just as before. After this the string looks a lot simpler (*9*), except for a tangled knot in the middle, which is irrelevant. Pass the thumb over the two strings that make a loop at the index finger, then under the nearer string of the little-finger loop, and back to where you started from. You may need to twist your hands a bit here (*10*).

The next step is unusual. Using the fingers of the right hand, pick up the string at the point *a* and lift it over the left thumb, a fraction of an inch away. Then repeat on the other hand. Be careful to pick up the string above the string from the little finger that crosses it. If you've done this correctly, you'll end up with (*11*)—again with the details of the knotty middle omitted.

Almost there. The final step is easier to do than to describe. Turn your thumbs to point toward each other, pass them through the holes marked *b* and bring them up on the near side. Then point your index finger into the holes marked *c* in (*12*). Carefully slip the string off the little fingers and turn your palms smoothly outward to stretch the string out. You should, after a bit of practice, get (*13*)—Indian diamonds in all their glory.

These two examples have merely scratched the surface of string figures. If you want to know more, take a look at *String Figures and How to Make Them*, by Caroline F. Jayne (Dover Publications, 1975). It is chastening to realize that for all its amazing capabilities, today's topology cannot yet come to grips with an ancient childhood game. Yet I have a strong suspicion that the ideas behind topology can rise to the challenge. So you can accept the challenge and invent cat's cradle calculus—or you can just have fun exercising your mathematical muscles by making elegant shapes from a simple loop of string. SA

***INDIAN DIAMONDS** is a sequence that can be formed by only one person. So a calculus for this game should be easier to construct than for cat's cradle. The dots represent the fingers of two hands, around which the string is looped. The excruciatingly complex sequence of moves (detailed in the text) leads to a surprisingly simple pattern.*

FEEDBACK

The May column focused on finding primes; its mailbag included one idea I can't resist telling you about. It is from *Visions of the Future*, edited by Clifford A. Pickover (Science Reviews, Northwood, England, 1992); the precise article (pages 151–157) is "Molecular Biology and Futuristic Problem Solving," by Mels Sluyser and Erik L. L. Sonnhammer of the Netherlands Cancer Institute in Amsterdam.

Sluyser and Sonnhammer take software used to study DNA and RNA and apply it to sequences of prime numbers. RNA sequences involve four bases—*A, U, C, G*—that bond in pairs to form the famous double helix. Sequences of biological significance are expected to possess some nonrandomness, because patterns in the RNA can cause it to fold into more stable configurations. These have less "free energy" than random, unfolded sequences.

The article shows that sequences of primes can produce significant results when interpreted as RNA sequences. A side effect is that certain new kinds of regularity in primes become apparent. The starting point is the "parity" of a prime. Take a prime, such as 23, and write it in binary notation, 10111. Count the number of 1's, here 4, and determine whether that number is even or odd. Here it is even, so 23 has "even" parity. Take the sequence of primes 2, 3, 5, 7, 11, 13, 17, 19, ... and split them into pairs: [2, 3], [5, 7], [11, 13], [17, 19] and so on. Work out the corresponding parities (I'll use "E" for even and "O" for odd) to get [O,E], [E,O], [O,O], [E,O]....

Now let [O,O] = A, [E,E] = U, [O,E] = C, and [E,O] = G, continuing along the sequence of primes. (This choice is arbitrary.) Here the first 20 pairs yield *CGAGUACCACAUCACACGCA*. Now use standard software to compute the folded configuration of such an RNA sequence. The free energy achieved is –256.9 kilocalories per mole, whereas random sequences of similar length yield, on average, free energies of –243.6—significantly bigger. So RNA structure techniques suggest that there are patterns, of some kind, in the sequence of primes. *—I.S.*

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REVIEWS AND COMMENTARIES

The Scientific American Young Readers Book Awards

by Philip and Phylis Morrison

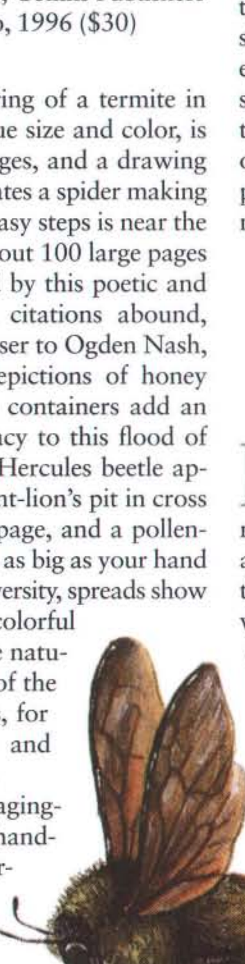
Among many hundreds received, we found these two dozen or so children's books within science the most winning. We hope our readers will choose a book or two to enjoy with a young person they know.

LIFE

Dragonfly Beetle Butterfly Bee
WRITTEN, LETTERED AND PAINTED
BY MARYJO KOCH
Swans Island Books, Collins Publishers
San Francisco, 1996 ($30)

A careful rendering of a termite in amber, at true size and color, is close to the first pages, and a drawing sequence that animates a spider making her orb web in 12 easy steps is near the end. In between, about 100 large pages are dazzlingly filled by this poetic and precise artist. Apt citations abound, from Edmund Spenser to Ogden Nash, and painstaking depictions of honey jars and bug spray containers add an insouciant immediacy to this flood of small paintings. A Hercules beetle appears full size, an ant-lion's pit in cross section takes up a page, and a pollen-carrying bumblebee as big as your hand brings detail. For diversity, spreads show us many dozens of colorful images, evoking the natural history albums of the past for dragonflies, for beetles, for wasps and bees, for butterflies.

All the text is engagingly hand-lettered or handwritten. On one sparingly simple page we read a maxim by Emily Dickinson on making a prairie: "It takes a clover and one bee." We see one bee but no clover. If much else is missing, we don't know what it is. (Spider kin, the arachnids, are here for completeness.) Some book!


MARYJO KOCH

Big and Little
BY STEVE JENKINS
Cut-paper collages. Houghton Mifflin Company, Boston, 1996 ($14.95)

Twelve pairs of animals appear posed together here, page after page. The crisp images are eye-catching, colored-paper cutouts on a paper-white ground. Each pair shown is similar in kind but contrasting in size: a big tiger towers over a little house cat; a rock python—which winds over three pages—stares at a coral snake; a gorilla watches a pygmy marmoset. The scale is the same for all, so that beginners and even the read-to gather the important message of diversity in size. A couple of detailed pages of text provide much more information for the better young readers.

Pigeons
BY DOROTHY HINSHAW PATENT
Color photographs by William Muñoz. Clarion Books, New York, 1997 ($16)

Pigeons are completely at home in cities." Their ancestors were wild rock doves, a species of Europe, Asia and North Africa, long drawn to share the seed crops of humans. In turn they were domesticated, for some time raised as food for people, and bred as well for a wide variety of traits: color, behavior or plumage. The flocks in cities and towns worldwide are now mainly feral. They are a mix of gray rock doves, once living in cliffside cavities, with escaped pigeons bred from the wild species. "Living flowers," said one fancier.

Trained pigeons have been used to bear wartime messages since the Gallic Wars. The homing ability of pigeons is great; although we know some of the ways by which the birds navigate, including sun position and magnetic clues, the whole issue is far from settled. Racing Homers, the most developed of all breeds, are rather larger than most pigeons, and many return as fast as 50 miles an hour when carried 500 miles away. A million people still race pigeons the world around. In Belgium it is the national sport.

Pigeons live their urban lives out—their ways summarized in the book—as quick learners, with good memories of visual cues; they readily find food and water and sustain only a small danger from predators. They have been with us a very long time and are probably here to stay as long as we do.

Running Wild: Dispelling the Myths of the African Wild Dog
BY JOHN MCNUTT
AND LESLEY BOGGS
Color photographs by Hélène Heldring and Dave Hamman.
Smithsonian Institution Press, Washington, D.C., 1996 ($45)

At daybreak, the hungriest dog stirs first, usually the one that received the least from the last kill. After a while, all awaken, pups playing, elders rallying and nudging, until everyone is pepped up. The march starts out slowly in some random direction; the dogs warm up as they move across broken woods and grasslands, first at a walk, then a trot, breaking soon into a long, easy, loping run, good for a few miles. The morning hunt is on.

The chase ensues, brief, acute, complex, for both hunter and quarry are fast and numerous. Many dogs will split off, each to pursue its own impala, but any unsuccessful chase is broken off within a minute or under a mile. Some dog will have caught an impala, tearing the soft belly open with one swift slash. Within seconds other dogs engage, until the pack arrives to dismember the morning's kill in "surprising silence." The pack will hunt a second time that day by golden twilight. (A photograph here catches one such procession.)

This fine book is set among meadows

and lily pads in the wild Okavango Delta wetlands of northern Botswana. Only a couple of hundred packs of painted dogs remain in all Africa. These dogs of another genus resemble our domesticates too much to survive freely near us. A canine-borne distemper came to ravage the dogs of the grassland Serengeti a few years ago, and cattle raisers across Africa remain hostile to the dogs. No reports of a dog attack on humans are known.

Not written for very young people, this detailed and insightful story is told so directly from watching the animals that most readers old enough to know the facts of life will be fascinated. We humans have a little while to choose to maintain the presence of painted dogs, another social species that has for two or three million years lived in the shadow of our kind.

Tale of a Tadpole
BY BARBARA ANN PORTE
Illustrated with watercolors by Annie Cannon. Orchard Books, New York, 1997 ($15.95)

Francine comes home from the nature center with a tadpole the size of the end of her little finger—and a clear idea. She puts Fred in the goldfish bowl and daily feeds him a little fish food. Francine is patient; in a few weeks Fred has grown two small legs, one on each side of his tail. The miracle unfolds. Fred's arms appear and fatten; his eyes and grin get bigger. Only his tail—it nourishes the rest—shortens. But one day Fred is not to be found swimming in his tank. He sits high and dry on the stepping-stones, an entire little frog.

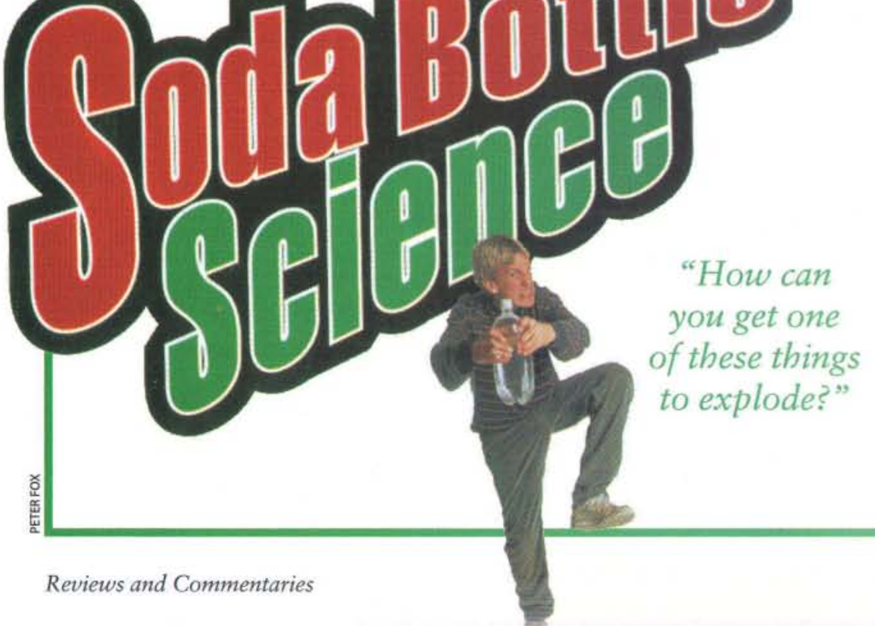
What now? Grandma and Grandpa visit, experienced gardeners. They make it clear: Fred is plainly a toad, a land frog. Fred is set fondly outside; he digs a hole, catches a fly and sets out on backyard life. Sound classification has its place; of course, it's not the name that most matters, but the facts, those bumps and short legs, wonderfully drawn along with the whole well-knit, cheerful family.

HANDS-ON SCIENCE

Zap Science
BY JOHN CASSIDY, PAUL DOHERTY AND PAT MURPHY
Klutz Press, Palo Alto, Calif., 1997 (spiralbound, $19.95; festooned with pieces of cool apparatus)

As before, the juggling senior Klutz, John Cassidy, and his friends have made a book as irreverent and direct as its subteen audience and as packed tight with good science experience as a quick trip to the Exploratorium in San Francisco, where Cassidy's co-authors work.

Electrostatic forces in action and change; visible passages from opaque to transparent to color under polarized light; a burning glass made from colorful Jell-O; vision experiments—all these possibilities open out of this text. The authors manage to avoid all but one antique piece of jargon: "likes repel, unlikes attract," and they tell you how to use that one well. Once again, here is a Klutz "fun-based, dirty-hands" trip to science in a book.



PETER FOX

Beluga Whales
BY TONY MARTIN
Voyageur Press, Stillwater, Minn., 1996 (paperbound, $14.95)

A shallow pond seen here in blue-green appears to shelter a school of gregarious white fish—but that's all wrong. This is no pond but the sea; these are not fish but surfacing white whales—small only among whales. They average 10 to 15 feet long, weigh in at a ton or more and are caught by a lens high aloft that shows up the horizontal tell-tails of their mammalian nature.

These rather mysterious animals are a treat, now on exhibit in many landlocked pens. Those who would admire them in wider waters can visit Churchill, Manitoba, in July and August, the same Hudson Bay port that after the freeze accommodates polar bears by the hundred. Readers will be moved to put in a good word everywhere to seek more icy room for the beluga.

LANGUAGE AND LOGIC

Exactly the Opposite
BY TANA HOBAN
Color photographs. Mulberry Books, William Morrow & Company, New York, 1997 (paperbound, $4.95)

This wordless book with about a dozen pairs of full-page color photographs holds a surprising depth of content for small kids, even for the read-to. Each exemplar is sharply recognizable, hands or sheep or a summer garden, and the power to grasp and express opposites is plainly a part of gaining language for us all. The sneaker pair is pretty surely tied and untied, but are hands extended and clenched, two plants spiny and smooth, bears big and small? No simple word game, even though it elicits words in all languages! Newly reprinted as a paperback, this book is a gem of economy of expression.

The Ring of Truth: An Original Irish Tale
BY TERESA BATEMAN
Illustrated by Omar Rayyan. Holiday House, New York, 1997 ($15.95)

A Symphony for the Sheep
BY C. M. MILLEN
Hand-colored woodcuts by Mary Azarian. Houghton Mifflin Company, Boston, 1996 ($14.95)

These two artful stories are set around the green hills of Donegal. *Ring* is no folktale but a delicious logical exercise, a fable built on the liar's paradox. It begins as a well-constructed story about one Patrick O'Kelley, a magnificent liar, who went off to a blarney contest to win a pot of gold. What happens is paradox. Even the illustrations are colorful in opposing ways: each holds a wildly romantic, even grotesque, portrayal of Patrick and what he saw, and yet most are framed in an evocation of the delicate illumination of such medieval masterpieces as the *Book of Kells*.

OMAR RAYYAN

Symphony is no folktale either but an original form of verse. Good-humored, rich woodcuts spin out a ewe and a ram, gentle shearing, the spinner at the wheel, washing and carding, swifts and skeins, knitter and weaver. The rhythm of the work is quietly present in the verse. Finally, the reader is asked to speak the refrains to hear the beat and, more, to ask four readers to make a round out of spoken meter. Here is a gift for little groups of kids and adults who have some feeling for fabric both in wool and in word.

PEOPLE AND TALES

Africatrek: A Journey by Bicycle through Africa
WRITTEN AND PHOTOGRAPHED IN COLOR BY DAN BUETTNER
Lerner Publications Company, Minneapolis, 1997 ($23.93)

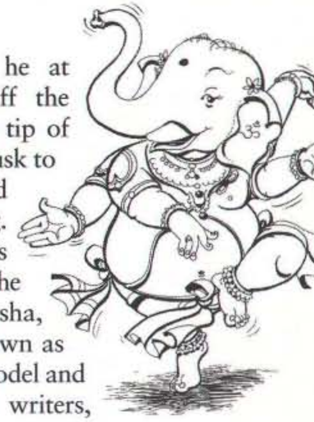
Dip your rear wheel into the sea at a Tunisian beach, northernmost point of the big continent, and your front wheel, 12,000 miles and nine months later, at the southernmost tip, the Cape of the Needles (to translate "Cape Agulhas"). From November 1992 to August 1993, you accompany riders as they bike the Africas, all six geographic regions: North Africa, the Sahara, West, Central, East and Southern Africa. Four admirable, well-loaded American aluminum bikes carried five regulars (no, not a tandem; one bike was shared by two African cyclists, each man available for half the months). In between came hard, hungry, even painful work, struggle, adventure and delight.

Near journey's end in late July, they entered South Africa. Soon they were a big deal in all the media, personally welcomed by the national leaders! It was campaign time for the first free election, when Nelson Mandela would be elected president. The cyclists, plainly four warm and successful partners under long stress, were two white Minnesotans, an African-American physician from Arizona and a savvy black Ugandan guide. A good omen at the birth of the new multiethnic state, but no more than what our few cyclists—and all of South Africa—deserved.

The Broken Tusk: Stories of the Hindu God Ganesha
RETOLD BY UMA KRISHNASWAMI
Drawings by Maniam Selven. Linnet Books, North Haven, Conn., 1996 ($19.95)

Elaborate tales of the gods inform current daily life more fluently in Hindu India than anywhere else, and of all the deities none is more popular and better suited for family and children than great Shiva's little son, rotund Ganesha with the elephant head. His image is everywhere as an omen of good fortune, in homes, shops and cars, as well as temples. Close to 20 of his legends are here, aided by lists of names and words and the characters who fill the pages, from the river Ganga to the fiery-red demon Sindura.

How did the many-armed god come to break the tip of a tusk? He was summoned, they say, to take dictation of the great poem *Mahabharata* from the lips of the sage who sang its volumes over the years. Scribe and poet bargained not to stop until their work was done. Suddenly, Ganesha's pen broke. Unwilling to risk losing any of the immortal verse, he at once broke off the smooth, sharp tip of his own right tusk to use as a pen and kept on writing. The tusk was ruined but not the bargain. Ganesha, honorably known as One-Tusk, a model and friend to all writers, helped India gain its written epic. Children hear the old tales of folly and wisdom, right and wrong, to this day. Warm, often funny, these line drawings and readable texts lead right to the heart of India.



MANIAM SELVEN

Growing Up in Coal Country
BY SUSAN CAMPBELL BARTOLETTI
Black-and-white photographs. Houghton Mifflin Company, Boston, 1996 ($16.95)

The minehead was dwarfed by the high breaker house. Within it a dozen narrow iron chutes led steeply down to the floor. New-mined hard coal—this is Pennsylvania at the place and time of anthracite—was tipped from the railcars, sized and shaken down the chutes to the floor. A number of boys sat on boards over the lowest part of each chute, stopping the falling coal with their feet, to pick out with bare hands—forbidden gloves earned a stick across the knuckles—and to toss aside the rock bits and debris that had come along.

Breaker boys were required by law to be over 14 years old. But the state had no compulsory birth registration, so a hard-strapped miner often got and filled in a 25-cent form to certify his son as "small for fourteen."

This book is by a miner's daughter, who has recaptured the simple human history of hard coal and hard times from family recollections and the printed record. The chapters tell us of mine mules, mine skills and mining villages, of disasters, and of paydays and good times, too. It closes with the great strike of 1902, five months of no work, leading to a real win under the solidarity of poor miners, whose leaders such as Mother Jones and Johnny Mitchell could speak for a proportion of the country's population threefold larger than this year's Teamster strikers at UPS.

Chidi Only Likes Blue: An African Book of Colors
TEXT AND PHOTOGRAPHS IN COLOR BY IFEOMA ONYEFULU
Cobblehill Books/Dutton (division of Penguin USA), New York, 1997 ($14.99)

Nneka has a little brother, Chidi. Sister and brother often play a game called Colors. "My favorite color is blue," because the sky is blue, Chidi always says, and his best shirt—we see it plainly—is blue, too. Their mother wonders if he knows any other color words. So Nneka shows him and us many other colors around their Nigerian village, and why she likes them.

We meet Great-Uncle in his formal red chief's cap. Next we see yellow piles of ground cassava for sale to make soup, special tasty green leaves that wrap delicious bean cakes, white chalk to mark wishes on the floor. And when Mother wears gold jewelry on special occasions, she looks as "pretty as the sunshine."

Nneka's was good teaching, so Mother made her small daughter a beautiful dress of all the colors she had enjoyed. "But Chidi still likes blue best of all!" This is a quietly engaging account of life far away, a life that both mirrors and contrasts with what most happy kids here will know.

EARTH AND SKY

Rain
BY PETER SPIER
With 84 watercolors. Bantam Doubleday Dell Picture Yearling Books, New York, 1997 (paperbound, $5.99)

As the gusts arrive, the rain pelts down. You can all but hear it. Twenty-five vivid pages are then crowded with inverted umbrellas, overflowing barrels, flooded wheelbarrows, puddles covered with spreading ripple rings, songbirds hiding, torrents running past the curbstone, swans and geese sailing downstream, until the two kids, soaking wet but utterly happy, go in at last. Their retreat is complete, once they pour water out of their boots through the open back door. Steamy baths help much, and the big wood blocks saved for a rainy day are built high. Cocoa and cookies, some TV, then a round roast carved nicely by father do their wonders. Still, it rains and rains after dark. Very late the moon sets, and the sun rises, and sister, brother and dog soon awaken to go out into the renewed sunshine we all enjoy. Experience!

Orbit: NASA Astronauts Photograph the Earth
BY JAY APT, MICHAEL HELFERT AND JUSTIN WILKINSON
Edited by Roger Ressmeyer. National Geographic Society, Washington, D.C., 1996 ($40)

About 200 men and women have flown on space shuttle orbits. Keen and educated professionals all, they work hard, but in their time off, they look out of 11 windows as the world passes by below. Since John Glenn talked his way into permission to carry a 35-millimeter camera aloft in 1962, all astronauts have had recognizable, if not indeed enviable, handheld cameras. They shot what interested them, whether by long-held private plan, on timely tips from the ground or, like most photographers, in the quick of the moment.

Their take on 56 shuttle flights during 30 years was above a quarter of a million snapshots. Apt (a physicist-astronaut), Helfert (a climatologist) and Wilkinson (a geographer), each long engaged with shuttle missions, undertook to extract from this treasure a book of sample images. They offer us about 130 selections, arranged and mapped by continent. Here they are, large, gleaming, painterly, full of meaning, yet within the scope of what imaginative kids who take pictures can interpret.

Photographer Ressmeyer (overall editor) arranged to scan and digitize for reproduction the flight originals themselves, thereby evading the "dupes of dupes" that crowd and dilute all big, busy archives, to make these chosen views both beautiful and permanent.

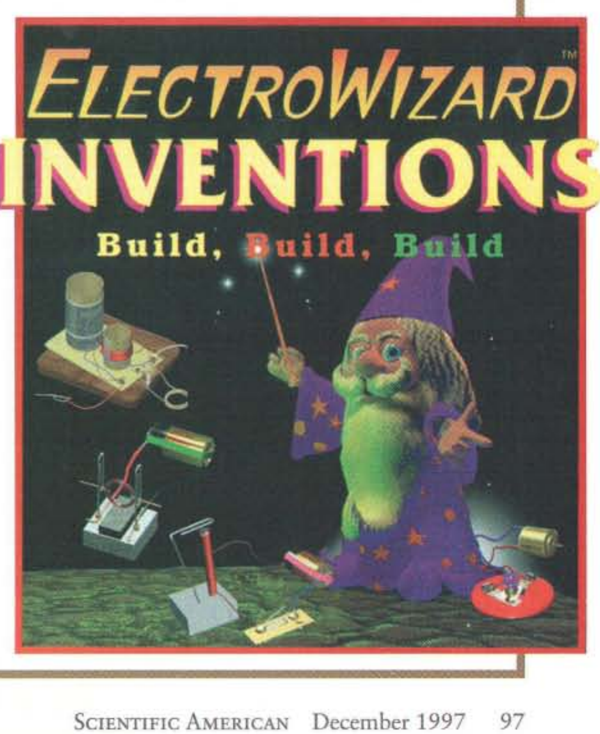
HANDS-ON SCIENCE

ElectroWizard Inventions: Build, Build, Build
BY PENNY NORMAN
Artwork by Art Huff. Norman and Globus, 1997 (Telephone: 510-222-2638; fax: 510-223-6953) ($19.95; boxed kit of materials with booklet)

Build them, and they will work: a simple spinning motor, a generator, a telegraph, a relay and an AM radio. But that is not all. Here all right is a well-designed how-to-do it book and kit, but it is far more than that.

The time-honored student motor—a simply wound coil, a ceramic magnet and some visible hardware—is yours to put together, embedded brilliantly into a web of evidence about how it works. First, a variety of coils are made familiar. Then step-by-step construction, visibly not hard but needing care, is helped by a troubleshooting list. Test your motor by watching a nearby compass deflect as you move the coil by hand. Test again, now watching a bulb in a series that flickers as the motor whirs away. Add and subtract magnets, cells, turns of wire. Look at your coil ends to note that what you have is really half a motor, inertially assisted—and you can prove it.

This box holds a triumph of cheerful hands-on, minds-on teaching at a distance, a really difficult mission.



ART HUFF

TECHNOLOGIES

Sarah's House
BY ERIC THOMAS
Carousel doll's house with press-out pieces. DK Publishing, New York (distributed in the U.S. by Houghton Mifflin Company, Boston), 1996 ($19.95)

Open the large, thin book with a little care, and you unfold a colorful paper dollhouse interior of eight intricately detailed rooms on two circular floors. The stiff covers become one inner wall of four, with all the rooms wide open to the visitor. An entrance hall displays the staircase and its elegant balustrade; upstairs a door opens to the parents' bedroom. Sarah shares the next room with her little brother. Open the wardrobe doors to view the children's clothing. Above Sarah's bed hangs a framed set of butterflies. And she has a tiny dollhouse all her own.

Downstairs the kitchen is most inviting, with its big coal stove and fine display of china. The sunroom has a door that opens on a pleasant garden, not to be visited. The family is here in paper press-out form, with their dog. They enjoy electric lamps (all paper, of course) and a gas water heater. We would judge that this work represents a well-to-do household near London about 100 years ago, in a cleverly truncated, portable form with much loving detail, even to silvery mirrors.

The Brooklyn Bridge
BY ELIZABETH MANN
Illustrated in color by Alan Witschonke. Mikaya Press, New York (distributed in North America by Firefly Books, Willowdale, Ontario), 1996 ($18.95)

Bridges
BY ETTA KANER
Illustrated in color by Pat Cupples. Kids Can Press, Toronto, 1994 (paperbound, $10.95)

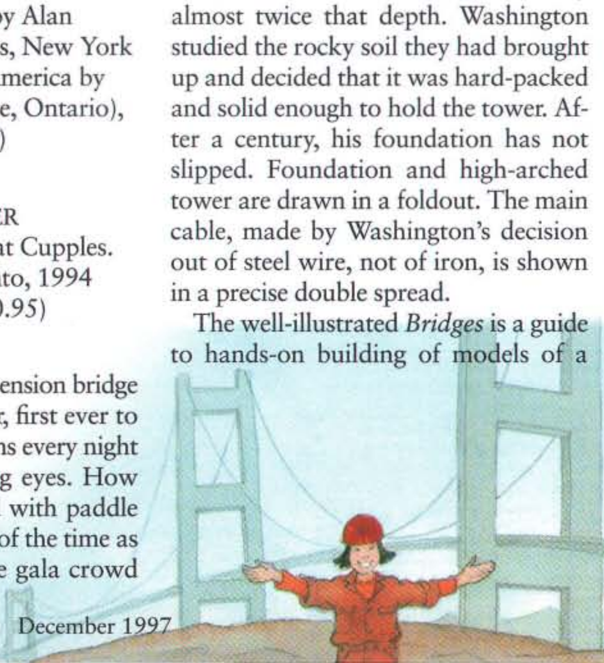
That stunning old suspension bridge across the East River, first ever to be electrically lit, still gleams every night to New Yorkers' admiring eyes. How the East River was dotted with paddle wheelers and sailing ships of the time as fireworks flared above the gala crowd when the bridge opened in May 1883!

This compact, image-filled book centers on the extraordinary family whose monument it has so long been. Bridge builder John Roebling, with a proud record of other bridges, conceived the idea one icy night on the ferry, promoted it for 15 years and at last designed it.

His son, Washington, an engineer and a Union colonel in the Civil War, became chief engineer at the age of 32 after his father died in an accident a year or two before construction began. Within a year he himself was forced to supervise only through binoculars from his home in Washington Heights, bedridden with the pain and paralysis of the bends, contracted in heroic fire fighting under high air pressure within an underwater wood caisson. The rising towers astonished people—25 stories high in a city then mainly five-storied—and the wire-spinning across the river was long a public aerial wonder.

Three major features of the bridge are well served by special graphics. One page of drawings treats the caissons below the towers. Each was an inverted wood "cup," a big, floorless building as watertight as a ship, holding compressed air, weighted and sunk to the riverbed to prepare the tower foundations. A hundred men worked by candlelight in each pressurized space, to scoop and pound through long, water-filled shafts to bedrock below. When they left, they filled the air spaces with concrete. Despite the earlier tragic fire, the Brooklyn side was far easier, for bedrock was reached only 40 feet deep. Across the river, bedrock had not been found by almost twice that depth. Washington studied the rocky soil they had brought up and decided that it was hard-packed and solid enough to hold the tower. After a century, his foundation has not slipped. Foundation and high-arched tower are drawn in a foldout. The main cable, made by Washington's decision out of steel wire, not of iron, is shown in a precise double spread.

The well-illustrated *Bridges* is a guide to hands-on building of models of a dozen sorts. It makes clear the pushes and pulls that underlie the mechanics and materials of bridge design at a level suited for grade school kids. Make a suspension bridge? Collect two matching straight chairs, two pieces of string, an old cardboard carton, some heavy books, and don't forget the Roeblings.



PAT CUPPLES

LAB SCIENCE

Shadow Games: A Book of Hand and Puppet Shadows
BY THE EDITORS
Klutz Press, Palo Alto, Calif., 1996 (spiralbound, $10.95; shadow cards and flashlight included)

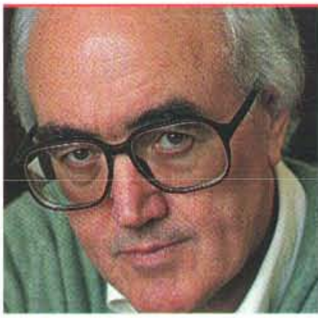
Turn down the lights, switch on the flashlight and check out shadow patterns your hand can cast. Add a rubber glove, or a pair of picnic forks, to see even stranger scenes; a couple of cards of monsters with glowing eyes are included for the younger set. A final pair of pages helps to model solar eclipses, those big shadows in the sky.

The Science Explorer Out and About: Fantastic Science Experiments Your Family Can Do Anywhere
BY PAT MURPHY, ELLEN KLAGES, LINDA SHORE AND THE STAFF OF THE EXPLORATORIUM
Illustrated by Jason Gorski. Owl Books, Henry Holt and Company, 1997 (paperbound, $12.95)

The kitchen table is a magnet for home experiments, given that the kitchen is not so far different from a lab. The staff of the Exploratorium in San Francisco has put together a sensible and attractive set of more varied activities for families, indoors and out, rain or shine, with what is around the house or what it is fun to go and get.

The drawings and questions here are fine models for this thoughtful search for new experience. Take your time. A small flashlight will let you shadow a wineglass from above, maybe through a card you cut to cast unusual shadows. Language also can open lots of new experiences. Try sentences without words: R U O K? Mix and match sets of words and find friends who use different names for familiar objects. Here are 100 pages for starters—and don't neglect family field trips around and about. SA

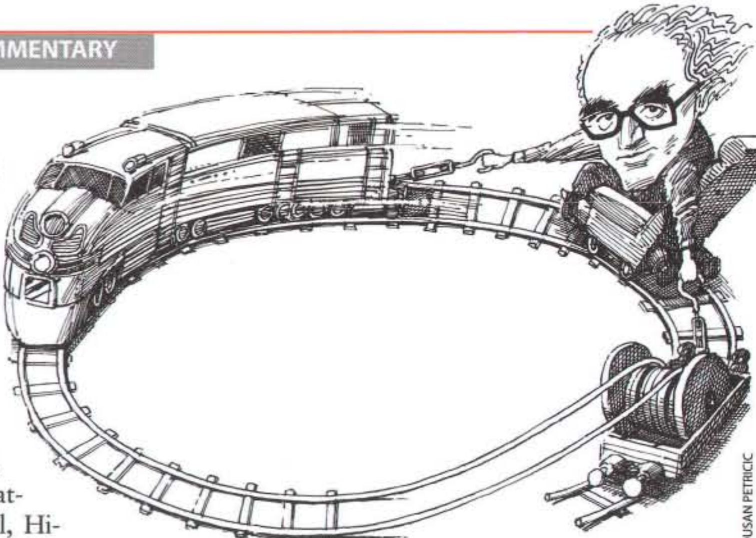
COMMENTARY



CONNECTIONS

by James Burke

On Track



DUSAN PETRICIC

I was on a train the other day, sipping a cold beer in the bar and thinking how, when I was a kid, railcars used to go clackety-clack, and now they just hum smoothly along. On continuous welded track, I believe it's called. Anyway, behind the bar on my train was a small fridge with "Linde" written on it. And I remembered reading somewhere that Carl von Linde, one of the inventors of the refrigerator, had been put up to his chilly endeavors by the local brewers who wanted to keep their vats cool so they could make their amber nectar in summer. This, while Linde was also working as a locomotive engineer. With instant coincidences like that, I knew I was onto a column.

Sure enough, Linde triggered more than trains, fridges and beer. In 1868 he started teaching at the Munich Technical College, and a year later he was inspiring a student who'd had a lonely childhood and was fixated on fuel efficiency. Well, it takes all kinds. The young man in question did little about his fixation—while selling Linde's refrigerators—until 1897, when he came up with a wonder engine that was reputed to run on anything from coal dust to peanut oil. And in petroleum-starved Europe, that was sweet music to anybody with haulage in mind. This turned out to be everybody from destroyer captains to farmers. Which was why Rudolf Diesel became wealthy and renowned overnight. So let's hear it for lonely childhoods and fixations.

Much of Diesel's sudden fortune came from the sale of distribution rights. The one for the British Empire was awarded to an American, Hiram Maxim, who did so well by Britain it eventually made him a Sir. In 1884 he had come up with the first successful automatic machine gun, which was then immediately adopted in one form or another by every major military power. Another case, as happened to Diesel, of the world beating a path (well, Hiram *had* also devised an improved mousetrap). Maxim's gun was the deadly weapon that would change the world by removing hundreds of thousands of troops from it during World War I.

Nowhere was the slaughter more heroic than in the air, where the machine gun spawned a new comic-book character: the fighter-pilot ace. None more celebrated than the Prussian daredevil aristocrat Manfred von Richthofen, a.k.a. the Red Baron, who notched up 80 kills, ran a squadron known (long before Monty Python) as the Flying Circus and who was reputed to have said,

Well, Hiram had *also devised an improved mousetrap.*

"When I have shot down an Englishman, my hunting passion is satisfied for a quarter of an hour."

In the end, Manfred won more medals than he could wear at one time and was feted by his fellow officers as the only man who could spin out of a dogfight upside down and still know instantly which way was home.

In a manner of speaking, so could his grand-uncle Ferdinand. That is to say, he was a geographer. Went to California, where he reported on the Comstock Lode. Then wrote the first definitive study of China, in which he illustrated the effect of topography on the economy. Then back to Germany, where (thanks to friends in very high places) he was given the chair of geography at Leipzig. Ferdinand's real contribution to the sum of human knowledge was his invention of chorography (how an area is made up of many smaller units) and chorology (how these units interreact).

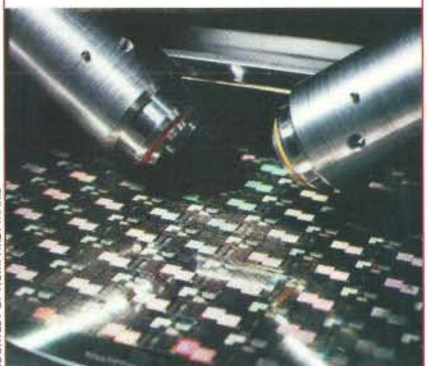
Ferdinand's successor at Leipzig was a guy named Ritter, who introduced humans into the geographical equation. Largely a spin-off from Romanticism, Ritter's interest in human geography (he invented it) originated in the man-nature relationship explicated a generation earlier by J. G. von Herder, man of letters. Ritter was also influenced by a single meeting with adventurer-explorer Alexander von Humboldt, who had, in 1804, just got back from five years in South America, where he had climbed the Andes and found the magnetic equator, the Humboldt current and the source of the river Orinoco, on top of carrying out hundreds of astronomical measurements—have I said enough? Humboldt also gave maps the "relieved" look they have today. On his way home, by way of Virginia, he dropped by Monticello to visit his guru, Thomas Jefferson, who was, like him, an environmentalist before environmentalists.

To be fair, there was a bit more to Jefferson than ecology. Like being third president of the U.S. and designer of the Capitol Building in Richmond, Va. Although some have said the real credit should have gone to Charles-Louis Clerisseau, crack French draughtsman and pal of Jefferson's. Clerisseau never got his due from Robert Adam, either. The Scots architect who made neoclassicism the lifestyle of the rich and famous (at least in Britain) learned much of what he later turned to profit from Charles-Louis, when the two of them spent a couple of years together in Italy and

Continued on page 100

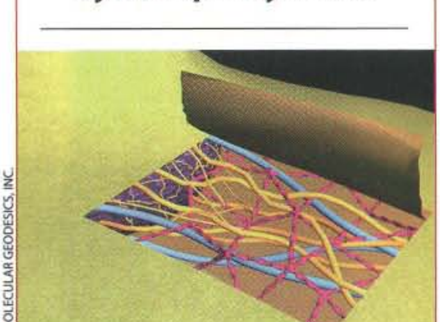
SCIENTIFIC AMERICAN

COMING IN THE JANUARY ISSUE...



COURTESY OF HUMPHREY MARIS

TRILLIONTH-OF-A-SECOND ULTRASOUND
by Humphrey Maris



MOLECULAR GEODESICS, INC.

THE ARCHITECTURE OF LIFE
by Donald E. Ingber

Also in January...

The Placebo Effect

The Ulysses Mission

Leonardo and the Wheellock

Gene Flow between Species

Burial of Radioactive Waste under the Seabed

ON SALE IN DECEMBER

Connections, continued from page 99

Dalmatia, sketching classical ruins. Back in Britain by 1758, Adam was so successful he was soon employing 3,000 craftsmen on his various stately-home rehab jobs. His trick was to make your crumbling pile look like the Parthenon.

One of the craftsmen Adam hired was Matthew Boulton (later to become James Watt's partner), who specialized in ormolu and all kinds of decorative metal frames. Boulton had a company that made everything from shoe buckles to sword hilts. This was why, in 1786, he knew what it took to design steam-driven coin-stamping machines, just at the time when counterfeiting had reached levels that worried the government enough to think about ordering replacement coinage. Boulton's machines could strike up to 120 coins a minute, depending on design complexity, and by 1792 he already had coinage contracts for the East India Company, the Sierra Leone Company, the American colonies, France, Bermuda and Madras. Five years later the British Mint caved in and asked him to make their new twopence, penny, halfpenny and farthing coins.

In 1816 coin design took a turn for the more elegant when the mint brought in an Italian engraver, Benedetto Pistrucci, and he brought in a reducing machine. Pistrucci proceeded to produce a large-scale cast-iron model of a new coin design and next traced out the model's contours with a pointer set on the end of a rigid arm. A spinning cutter, set farther down the arm, reproduced a scaled-down version of the design on a life-size die. Pistrucci used the gizmo to put St. George and the Dragon on the British sovereign and crown for the first time. The new classic look did not, however, land him the job of chief engraver. He was, after all, an alien.

A few years after Pistrucci, a bitter and disappointed man, passed away, the coin-design models were being electroplated and the dies made of steel, thanks to the work of William Roberts-Austen, new Master of the Mint and alloy freak. One of his steel alloys became known as austenite. And when he had finished making money making money, he went on to help make that train ride of mine as smooth as it was, with steel-alloy railroad tracks.

Here's where I get off. SA

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ANNUAL INDEX 1997

AUTHORS

ARTICLES, BY KEY WORDS

THE AMATEUR SCIENTIST
by Shawn Carlson

MATHEMATICAL RECREATIONS
by Ian Stewart

WORKING KNOWLEDGE

THE POLYGRAPH

by Joel Reicherter

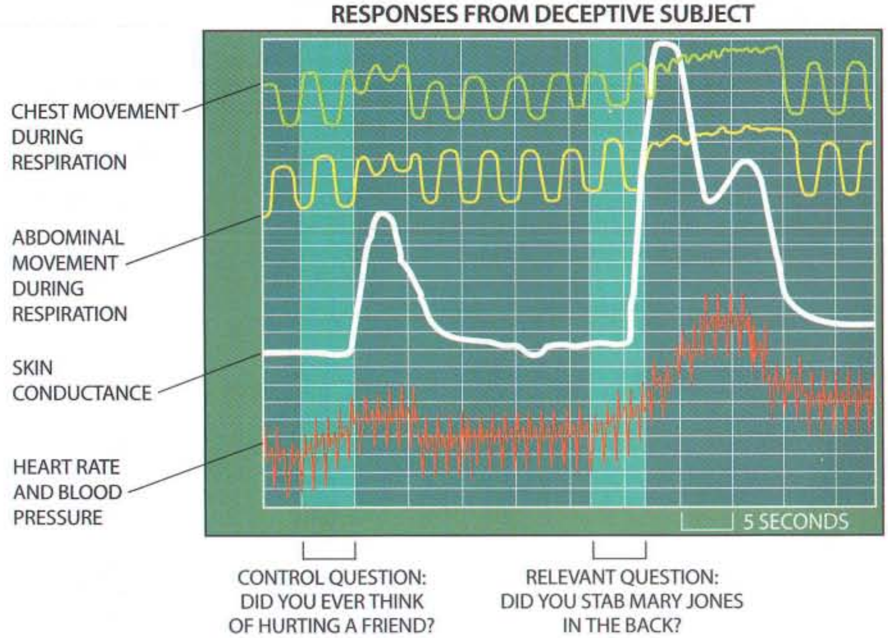
Professor and Coordinator of Human Anatomy and Physiology State University of New York at Farmingdale

The polygraph monitors physiological activity that occurs under the stress of deception. Respiration, heart rate, blood pressure and electrical conductivity of the skin alter in reaction to some types of questions perceived as threatening. That is why a lie, if told in response to such a question, can be detected by a polygraph.

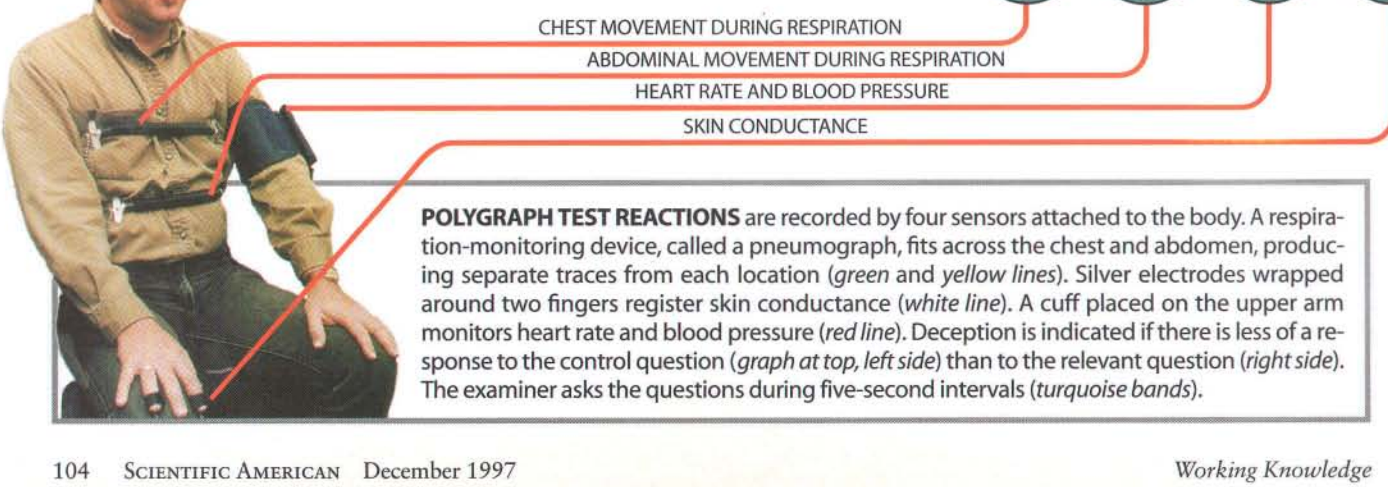
Polygraph testing consists of three phases: a pretest interview, the actual recording of the subject's physiological responses to test questions and an analysis of the recorded data. A typical polygraph examination consists of a few yes-or-no questions. Two or three "relevant" questions deal directly with the crime or dispute that caused the test to be administered. Other queries, known as control questions, relate to similar matters that may have occurred at another time.

The validity of polygraph tests rests on the theory that someone who is lying will perceive the relevant question ("Did you steal $500 from the office safe?") as more threatening than the vaguer control question ("Have you ever stolen something worth more than $25?"). Meanwhile the person telling the truth will find the control question more of a threat or an embarrassment. The instrumentation records physiological reactions to these questions. Examiners then assign numerical scores to the various responses that signify a degree of truthfulness or deceptiveness.

In the most advanced polygraph testing, a computer analyzes the waveforms that represent heart rate and blood pressure, skin conductance and respiratory dynamics. The computer's algorithms have been developed based on confirmed polygraph test results. This analytical innovation reduces the potential for test results being tainted by an examiner's bias or incompetence, thus bringing us one step closer to a truly objective method of lie detection.



ILLUSTRATIONS BY JOHN TOM SEETIN; PHOTOGRAPH BY GARY MOO YOUNG



POLYGRAPH TEST REACTIONS are recorded by four sensors attached to the body. A respiration-monitoring device, called a pneumograph, fits across the chest and abdomen, producing separate traces from each location (*green* and *yellow lines*). Silver electrodes wrapped around two fingers register skin conductance (*white line*). A cuff placed on the upper arm monitors heart rate and blood pressure (*red line*). Deception is indicated if there is less of a response to the control question (*graph at top, left side*) than to the relevant question (*right side*). The examiner asks the questions during five-second intervals (*turquoise bands*).